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U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Evaluation of Off-Axis Measurements Performed in an Anechoic Chamber

M. Kanda
J.C. Wyss

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[2] Some divisions within the center are located at Boulder, CO 80303.
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M. Kanda
J.C. Wyss

Electromagnetic Fields Division
Center for Electronics and Electrical Engineering
National Engineering Laboratory
National Bureau of Standards
Boulder, Colorado 80303

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M. Kanda and J. C. Wyss
Electromagnetic Fields Division
National Bureau of Standards
Boulder, CO 80303

Field strength versus distance from various source antennas is measured in a rectangular rf anechoic chamber on axes parallel to the boresight axis. An electrically small field probe is repeatedly scanned longitudinally away from the launch antenna and into the chamber. With each scan various parameters are changed, including: 1) horizontal and vertical position of the probe with respect to the center line of the launch antenna; 2) frequency, and 3) type of launch antenna. With the probe located 1 m off the center line and scanning between 2 and 6 m from the launch horn, the uncertainty due to being off the center line ranges from ±1 dB at 250 MHz to ±5.0 dB at 800 MHz and above. If the probe is within ±50 cm of center line, the uncertainty is no more than ±1.5 dB at 800 MHz; and, for ±25 cm from center line the uncertainty is further reduced to ±0.5 dB at 800 MHz.

Keywords: anechoic chamber; open-end waveguide; probe; pyramidal horn

1. Introduction

A side view of the rf anechoic chamber room is shown in figure 1. The chamber is illuminated by placing a pyramidal horn or an open-end waveguide (OEG) in a doorway with their apertures in the plane of the absorber points on the chamber wall. A receiving probe is placed on a computer controlled cart. Riding on precision tracks, the cart can move up to 6 m into the chamber, using stepper motors.

In a previous paper, FitzGerrell describes an evaluation of the anechoic chamber where measurements are made down the center line of the source antennas [1]. In that experiment electrically small dipoles or OEG transmitting antennas were located on the cart while source antennas, used as receivers, were placed in the door. Comparing the experimental results to theoretical calculations of the center-line field, FitzGerrell showed excellent agreement between the two. In addition he determined anechoic chamber errors due to reflections to range from -0.6 to +0.5 dB at 229 MHz up to ±0.04 dB at 18 GHz. These reflection errors appear as smooth oscillations in the experimental data.

In the experiment reported in this paper, the anechoic chamber errors due to off-axis misalignment of the receiving antenna with respect to the source antenna are determined. The error is measured by comparing center-line data with data taken at various distances off the center line. By quantifying this source of error, we will be able to provide criteria for alignment of the probes. This measurement will also be included in the anechoic chamber error-budget analysis that is presently being performed [2].

2. Experiment Setup

In the present chamber-evaluation test, the source antennas are located at the doorway and the receiving probe is located on the movable cart (fig. 1). The receiving probe, an electric-field monitor designated EFM-3, consists of a spatially isotropic, broadband (100 to 3,000 MHz) antenna developed by NBS [3]. The probe is connected to a receiver box by a nonperturbing, high-resistance cable. The receiver output ranges from 0 to 2 Vdc representing a field strength of 0 to 20 dB above 1 V/m at the probe. This probe output is put into the cart's on-board computer, where it is converted to a digital signal. The cart's computer also controls the stepper motors which move the cart back and forth along two precision guide rails. A laboratory computer, through a fiber optical data link, communicates with the cart's computer telling it to 1) digitize and transmit the probe output to the lab computer for storage on a floppy disk; and 2) move the cart a predetermined distance. For a typical scan, the probe would initially be manually set to 1.00 ± 0.005 m from the source antenna aperture. The source field would then be set to provide a 20 dB V/m (or 10 V/m) field reading on the receiver probe. The laboratory computer would then instruct the cart computer to move away at a constant rate from the source antenna and to simultaneously digitize a reading from the probe after each 5 cm movement. As each reading is taken and digitized, it is sent over a fiber-optic line back to the laboratory computer for storage and later manipulation.

The receiving probe is mounted on a 2-m wide by 2-m high wood frame that has holes drilled into it for holding the probe at eighteen different locations. As shown in figure 2, the center location (position 1) of the frame is along the center line of the source antenna. At each frequency, the probe would first be placed in position 1 for the first scan. To check the reproducibility of the measurement system, the position 1 scan would typically be repeated once or twice. For the same source frequency and field intensity, the probe would then be moved to other positions on the frame and the measurement scan repeated. By comparing the off-axis measurements (positions 2-9, 21-23, 41-43, 61-63) with the center line measurement (position 1), we are able to determine the anechoic chamber measurement error due to off-axis misalignment of source and receiver antennas.

To make the off-axis error evaluation meaningful, it is necessary to consider other variables of the measurement system that could contribute to or "mask" the off-axis error measurement. Those other variables will be discussed here: 1) The intensity stability of the field generation system was measured as a function of time for periods ranging from 0.5 to 2.0 h. In the first 30 min of warmup of the system, the power-level maximum variation is ±0.5 dB (one standard deviation). During the next 1.5 h, the power-level variation dropped to less than ±0.1 dB (one standard deviation). 2) The EFM-3 probe was calibrated versus electric-field strength at the beginning and ending of each day, and the daily variation between these measurements was found to be ±0.2 dB. Over nine days of measurement (where the probe batteries are recharged each night) the calibration error varied ±0.56 dB (one standard deviation). The calibration error from adjacent scan to scan (separated by a few minutes) should be no more than ±0.1 dB. 3) The uncertainty in the cart position was measured to be ±2 cm. 4) The source antenna is held in place vertically by a hydraulic lift which sags or drops about 1 cm/h. Before each scan the source antenna height was remeasured and adjusted to be within ±1 cm of the initial height on the first scan. 5) The uncertainty due to the placement of absorber material around a horn, transmitting at 800 MHz, and in the rest of the door was measured to be no more than ± 0.15 dB (one standard deviation) as shown in figures 3 and 4. Four separate scans are shown in figure 3: a) horn aperture plane aligned with tips of wall absorbers, no absorber in door area, b) horn moved 0.79 m into chamber, no absorber in door area, c) absorber added to side of horn, filling half of door area, and d) additional absorber added above and below the horn (the horn remained 0.79 m into the chamber in the last two scans). The variation of these measurements is shown in figure 4 where the standard deviation between the four scans is plotted at each point versus the distance from the horn. The worst value occurring after the 5 m mark is ±0.15 dB. These measurements are made with the receiving probe at the center line of the source antenna.

The overall reproducibility of a scan, determined for consecutive scans and for repeated scans on different days, is a measure of the total uncertainty due to all of the possible error sources already mentioned. With the source antenna transmitting at 800 MHz and the receiving probe placed on the center line of the source antenna (position 1 of fig. 2), four scans were made on one day. The probe was then removed and recalibrated. On the following day the probe was returned to the center line position and four additional scans were taken. In figure 5 the eight scans are plotted versus distance from the source antenna. Note that the eight scans form two groups of four scans each where the groups are separated by about 1.5 dB. The lower group represent the four scans on the first day while the upper group are the four scans on the second day. To measure the variability of the scans consider figure 6. The lower curve represents the point-by-point repeatability for the first four scans (the lower group of fig. 5) and does not exceed ±0.15 dB (one standard deviation). The upper curve is the point-by-point calculated standard deviation using all eight scans from both days. The upper curve gives a measure of the day-to-day repeatability of a measurement and equals ±0.5 dB at its worst. Where more precise measurements are needed on a day-to-day basis, the field can be set manually using a standard dipole antenna as a test probe to monitor the absolute field strength.

For the present work, the center-line scan is to be compared to off-axis line scans. Since the compared scans are taken one after another without changing the initially set field strength, the error from lack of reproducibility should be the same as the adjacent scan-to-scan reproducibility of ±0.15 dB.

3. Results and Conclusions

In figure 7a, the center-line scan (position 1 on frame) is plotted along with scans where the probe has been moved horizontally and vertically ±1 m (fig. 7b). An open-ended waveguide with 250-MHz output is used. In figure 8, a standard deviation is calculated for these five scans and shows that the off-axis error is less than ±0.8 dB from 2.3 to 5.2 m from the horn. In figure 9a, five more scans at 250 MHz are taken with the probe spacing now

±1.41 m (fig. 9b), and figure 10 shows that the off-axis error now increases to ±1.0 dB from 2.4 to 4.8 m.

With pyramidal horns instead of OEGs, the off-axis error gets larger as the frequency increases. At 600 MHz and 700 MHz only two off-axis scans are taken. These show that the off-axis error is now ±2.5 dB (one standard deviation) or less for 600 MHz, 2.5 to 5.9 m; and ±2.5 dB for 700 MHz at 3.0 to 5.9 m (see figs. 11 through 14.) At 800 MHz (figs. 15 and 16), the error was ±2.5 dB for 2.5 to 6.5 m; at 900 MHz (figs. 17 and 18), the error was ±2.5 dB for 2.5 to 6.5 m; and, at 1000 MHz (figs. 19 and 20), the error was ±3.0 dB for 2.5 to 6.5 m.

Clearly, the pyramidal horns at higher frequencies have a greater off-axis error contribution. Another way of putting this is to say that for equal error contributions, a smaller volume is available at higher frequencies. To investigate this smaller volume at higher frequencies, additional measurements were made at 800 MHz using a smaller offset on the probe. Figures 21 and 22 show that for a 75-cm offset, the error is less than ±2.0 dB; figures 23 and 24 show that a 50-cm offset yields an error value of ±1.4 dB; and, figures 25 and 26 show that a 25-cm offset yields an error value of ±0.6 dB (where error values are for 2.5 to 5.3 m distances from horn).

The results are summarized in table 1. In general a 1.0-m offset from center line can contribute an error of ±3.0 dB at high frequencies and only a ±0.8 dB error at lower frequencies. If the offset volume is reduced to less than ±25 cm from center line, the error will be less than ±1.0 dB at all frequencies.

In figure 27 the offset error (one standard deviation) is plotted versus offset distance at 800 MHz. To reduce the offset error to ±1.0 dB, the center line offset must be less than ±50 cm. This should be readily attainable in the present anechoic chamber arrangement.

Table 1. Error due to off-axis alignment.

Offset distance from center line (m)		0.25 (dB)	0.50 (dB)	0.75 (dB)	1.00 (dB)
Frequency (MHz)	Source antenna type				
250	OEG				±0.8
600	Horn				±2.5
700	Horn				±2.5
800	Horn	±0.5	±1.2	±2.0	±2.5
900	Horn				±2.5
1000	Horn				±3.0

4. References

[1] FitzGerrell, Richard G. Using free-space transmission loss for evaluating anechoic chamber performance. IEEE Trans. Electromagn. Compatib. EMC-24: 356; 1982.

[2] Kanda, M., to be published.

[3] Larsen, E. B. and Ries, F. X. Design and calibration of the NBS isotropic electric-field monitor (EFM-5), 0.2 to 1000 MHz. Nat. Bur. Stand. (U.S.) Tech Note 1033; 1981 March. 104 p.

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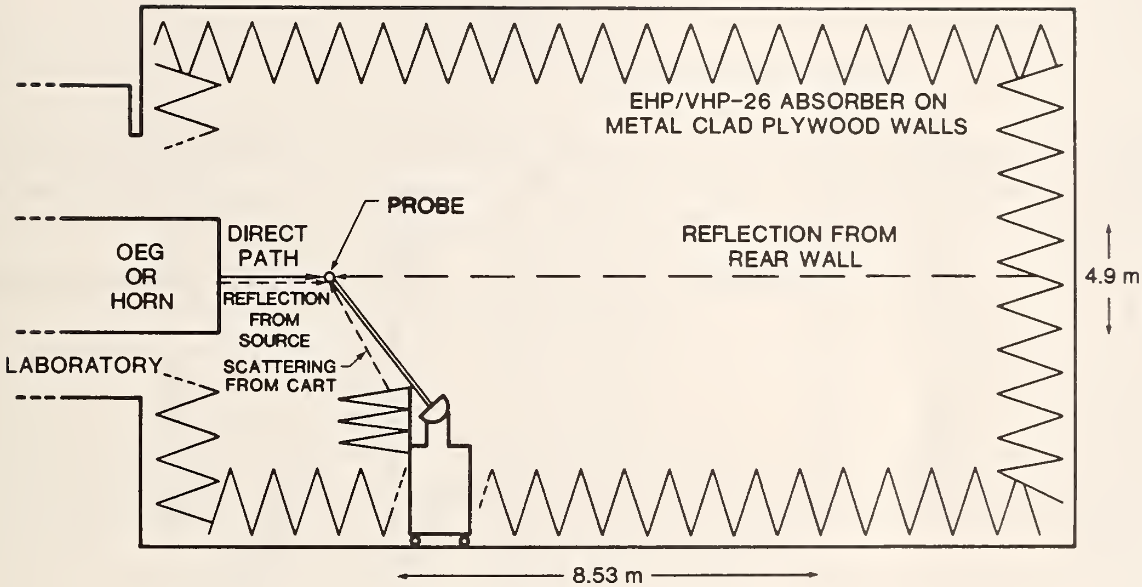


Figure 1. A side view of the NBS-Boulder Anechoic Chamber

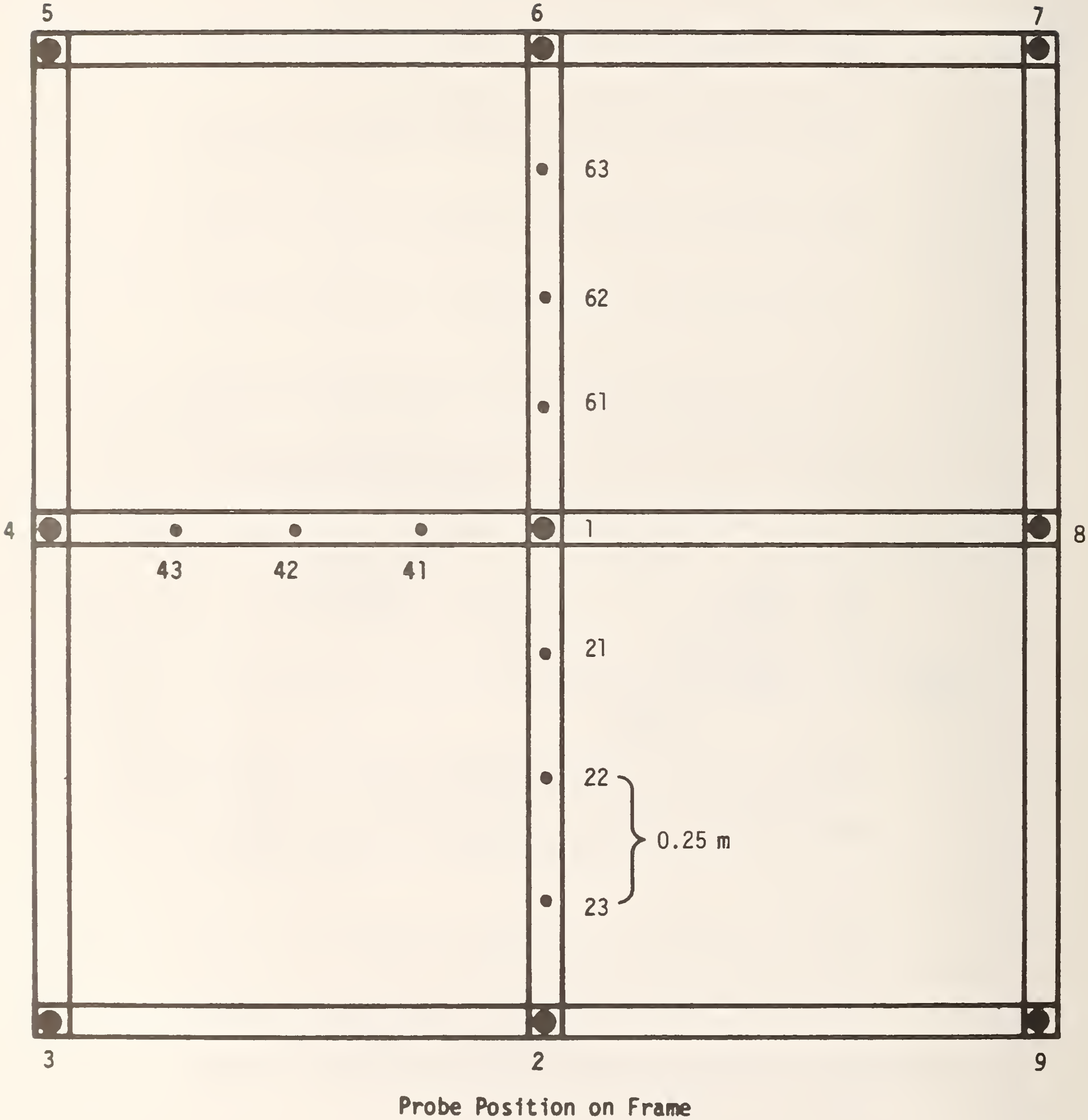


Figure 2. Frame used for holding probe on cart. Positions 1 through 9 are separated by 1 m intervals. The numbered positions (21-24, 41-44 and 61-64) are each separated by 25 cm.

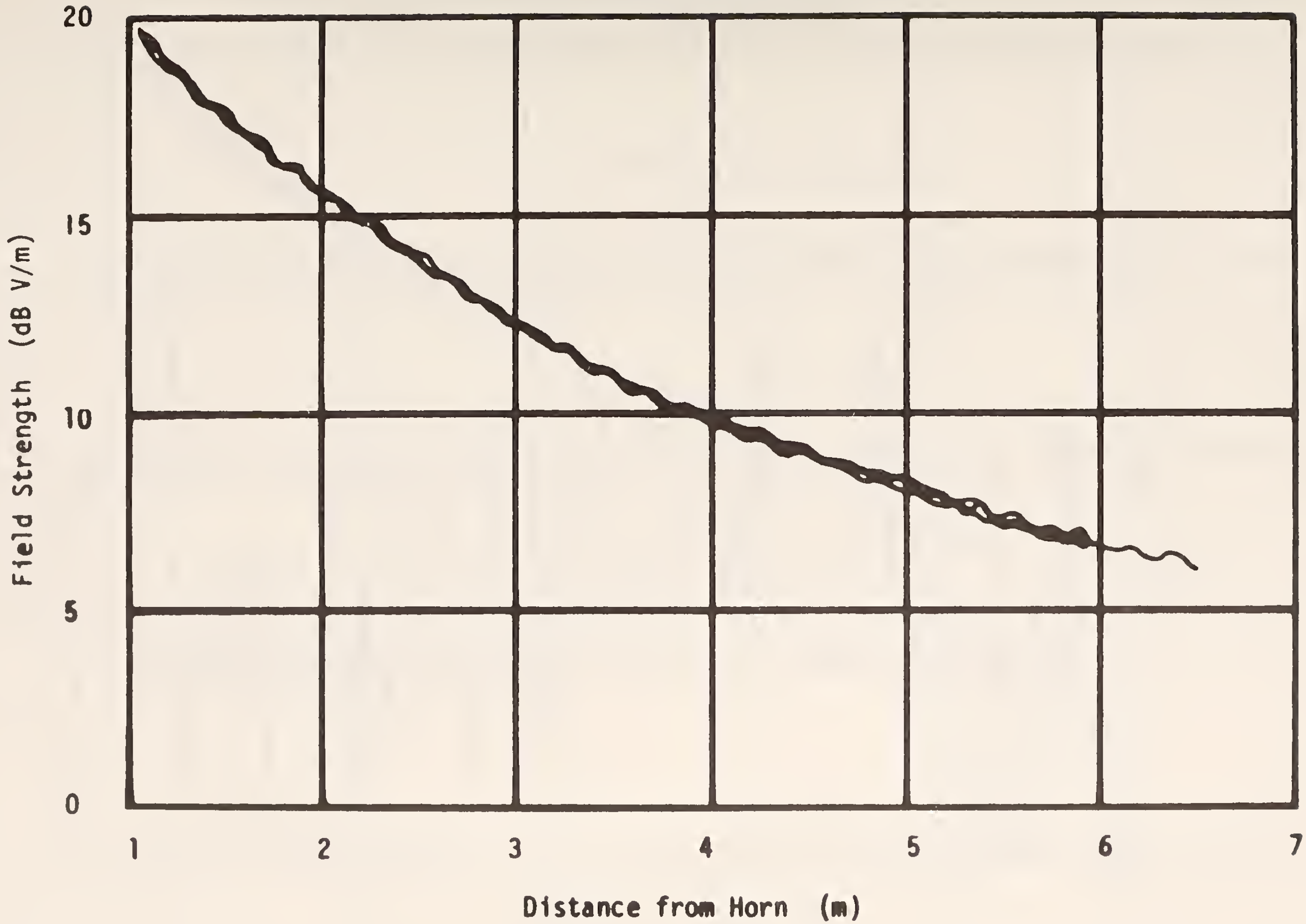


Figure 3. Field strength is plotted versus distance from horn for four separate scans at 800 MHz. The probe is at the center position (number 1 in fig. 2). For each scan, additional absorber was placed in doorway to the chamber and around the horn.

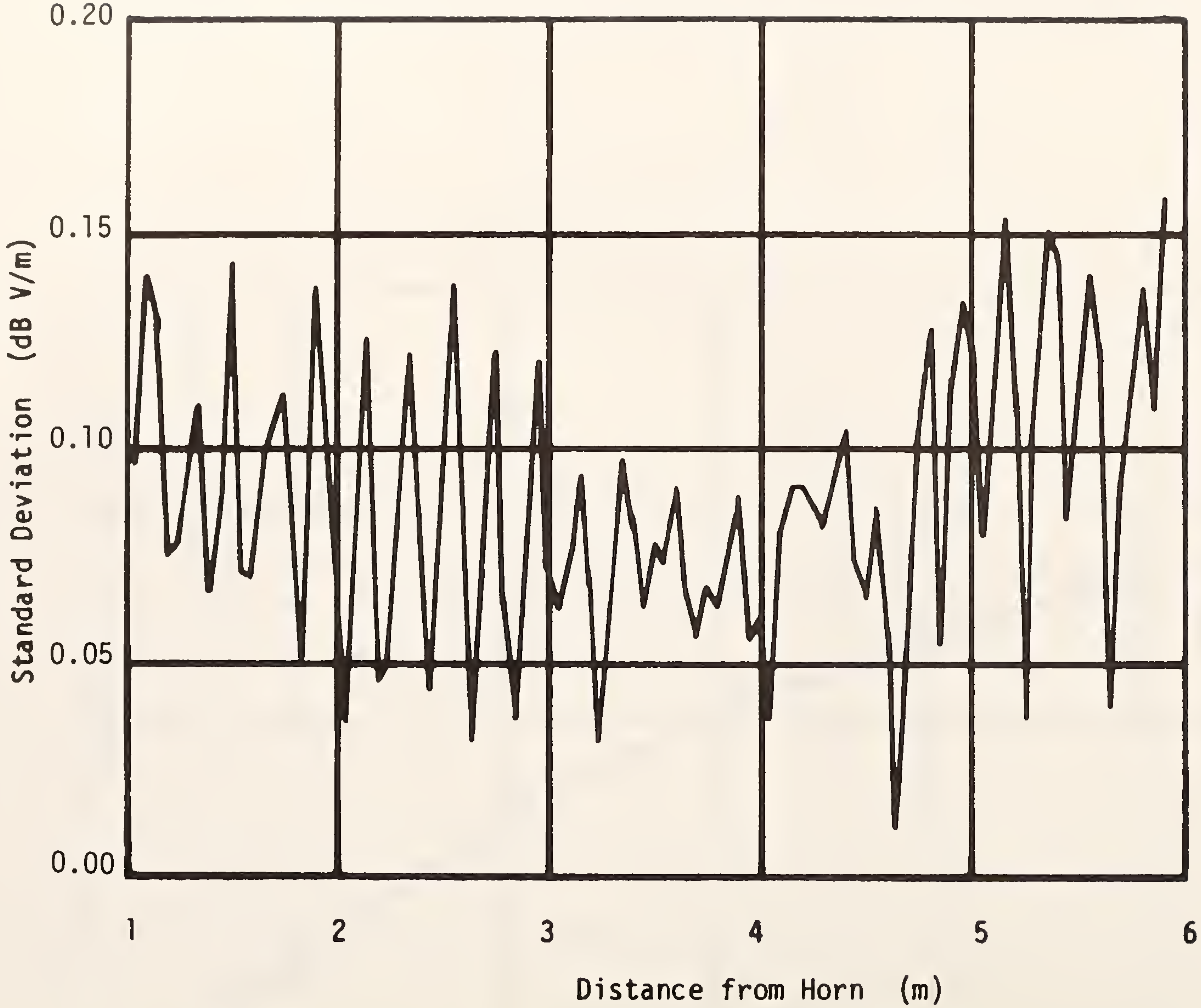


Figure 4. Standard deviation versus distance from horn is plotted. Using the four scans plotted in figure 3, a standard deviation is calculated at each point and plotted here.

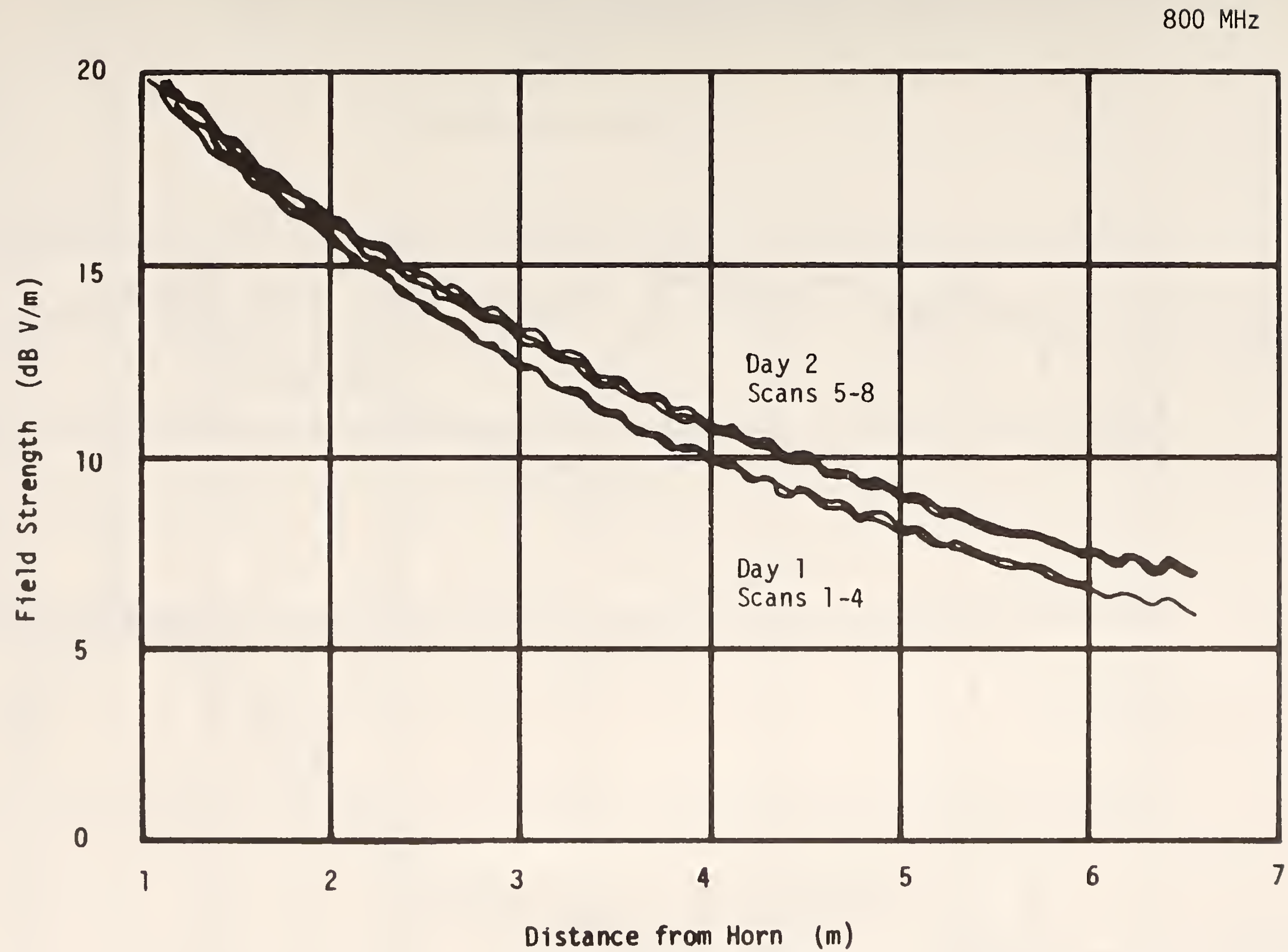


Figure 5. Field strength versus distance from horn is plotted for eight different runs taken on two different days. Four scans from the first day make up a lower group while the four scans on the second day form the upper group.

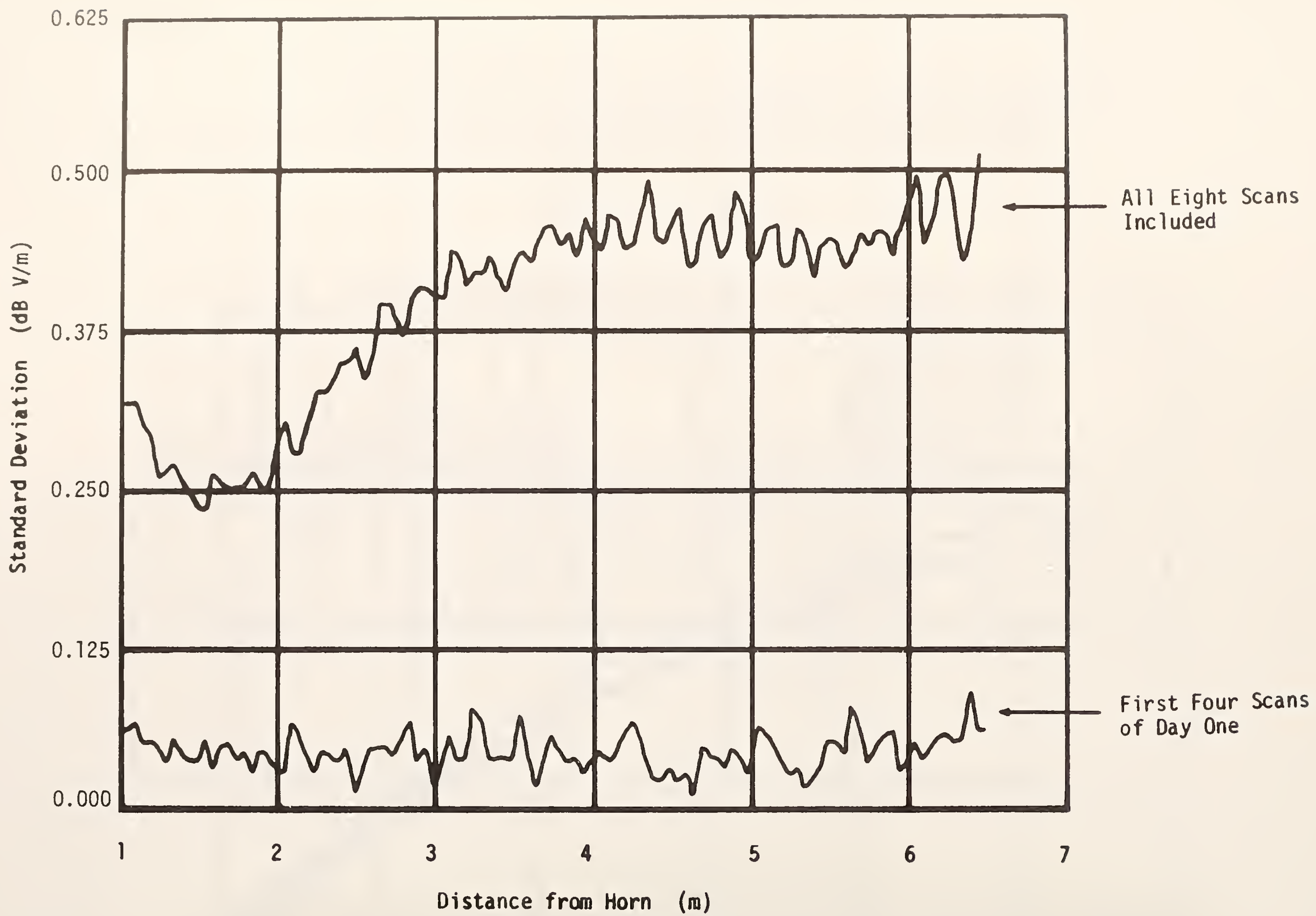
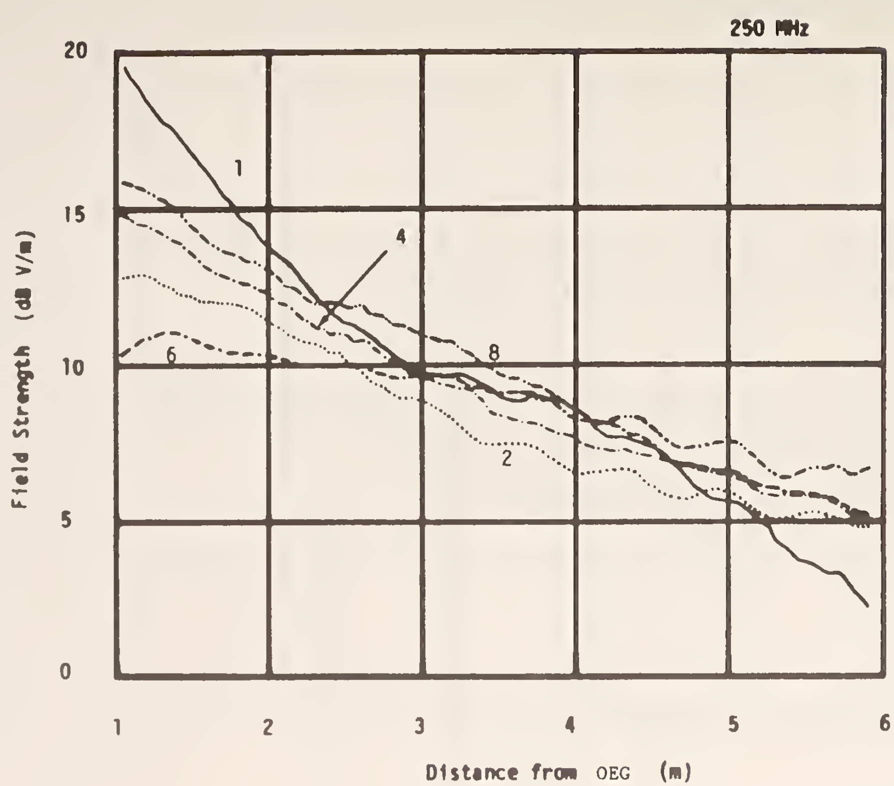


Figure 6. Standard deviation versus distance from horn is plotted. The lower curve is calculated from the four scans of the first day plotted in figure 5 (lower group). The upper scan results when all eight scans from both days are included.



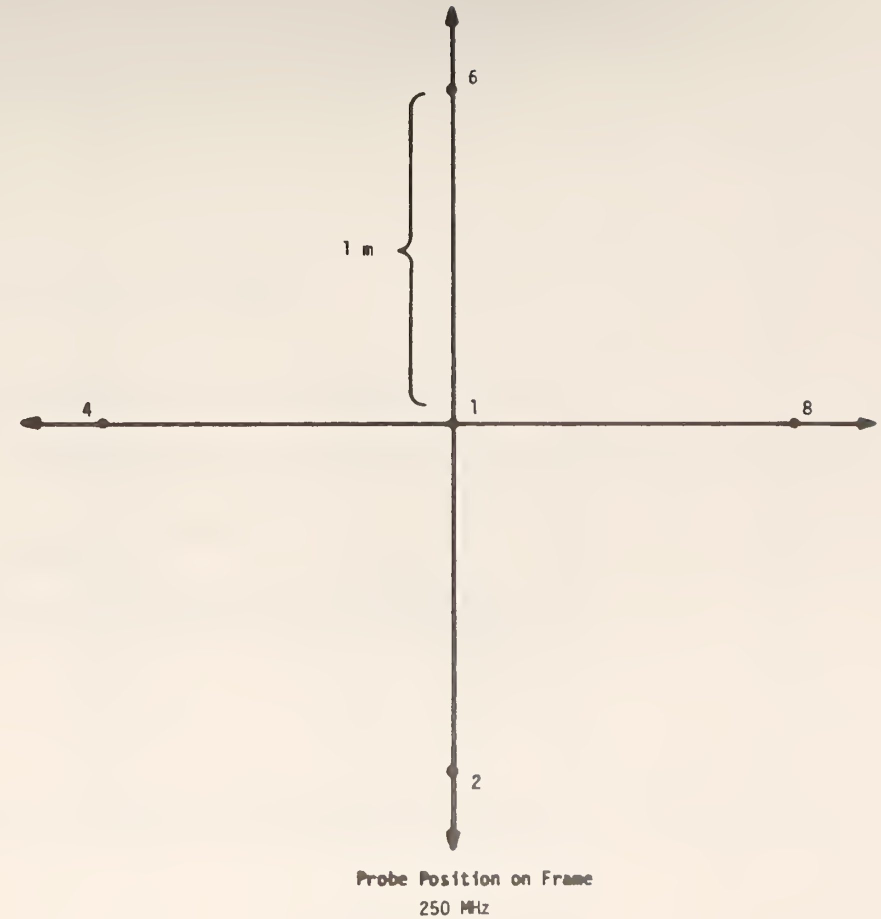


Figure 7. a) Field strength versus distance from OEG. Five scans are plotted for 250 MHz and include the center line, position 1 (solid line) and 1 m off-axis scans, positions 2, 4, 6, 8 (dashed lines). b) Shows positions of probe on frame.

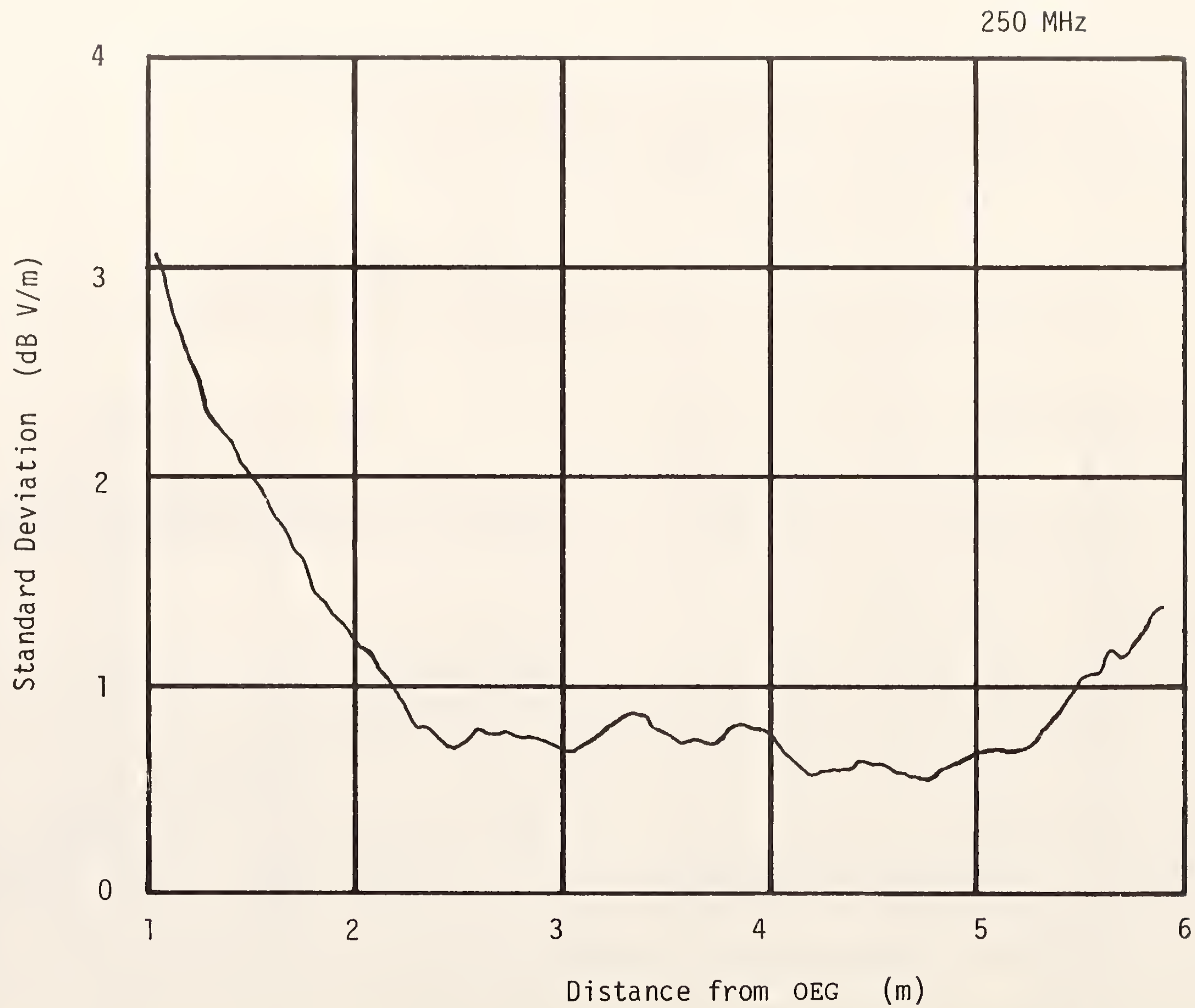


Figure 8. Standard deviation versus distance from OEG using scans of figure 7.

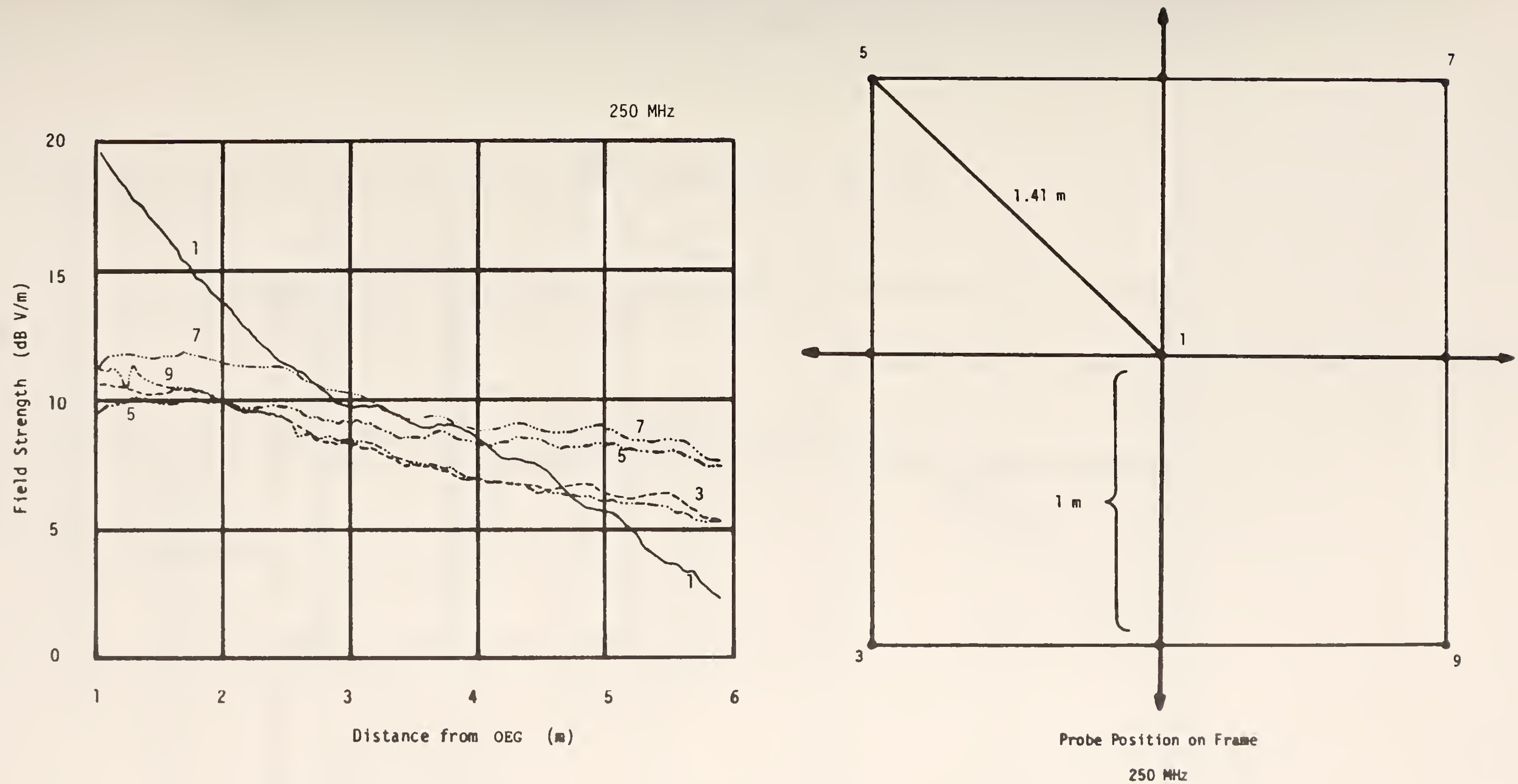


Figure 9. a) Field strength versus distance from OEG. Five scans are plotted for 250 MHz and include the center line, position 1 (solid line) and the 1.4 m off-axis scans, positions 3, 5, 7, 9 (dashed lines). b) Shows positions 3, 5, 7, 9 (dashed lines).

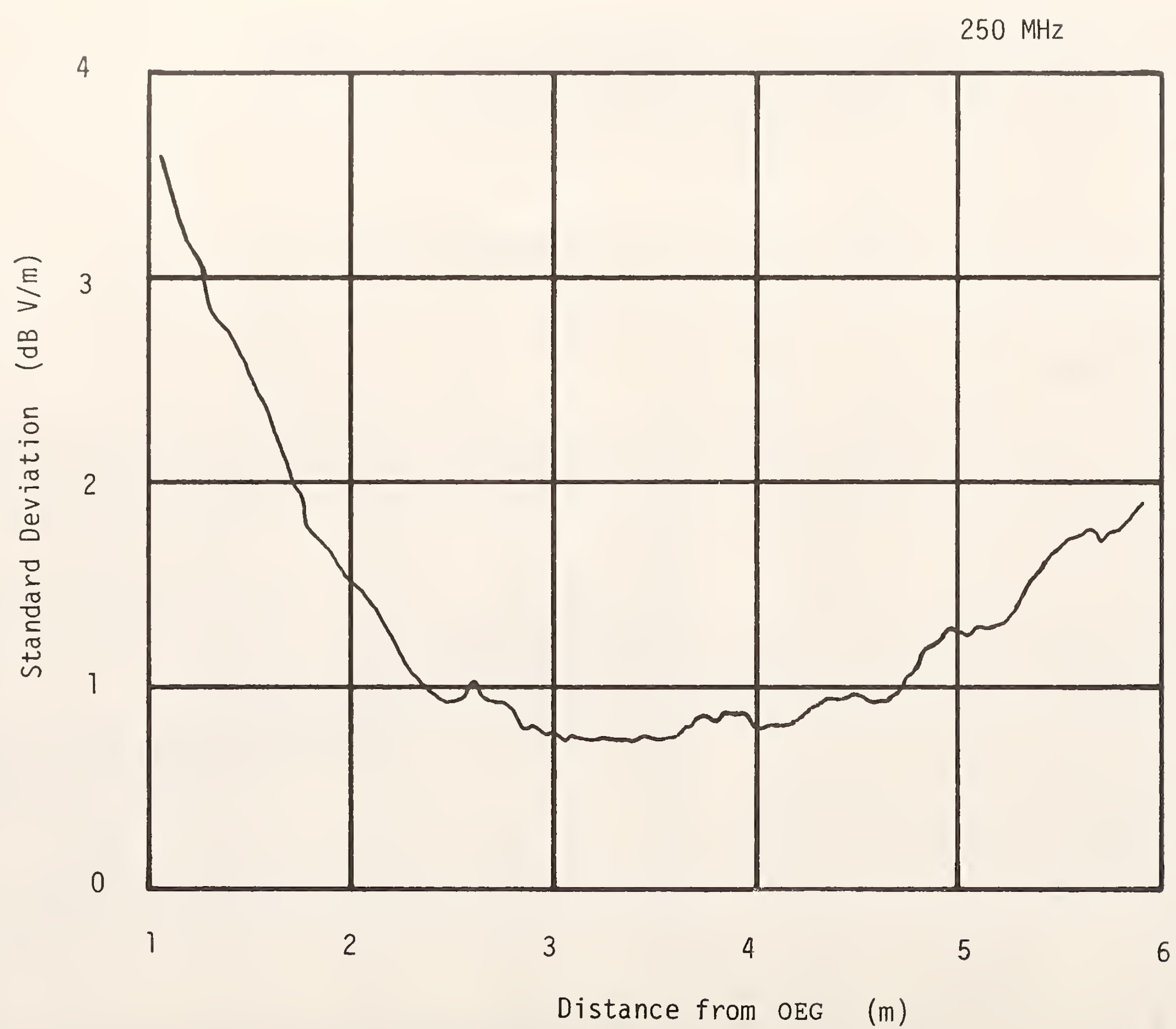
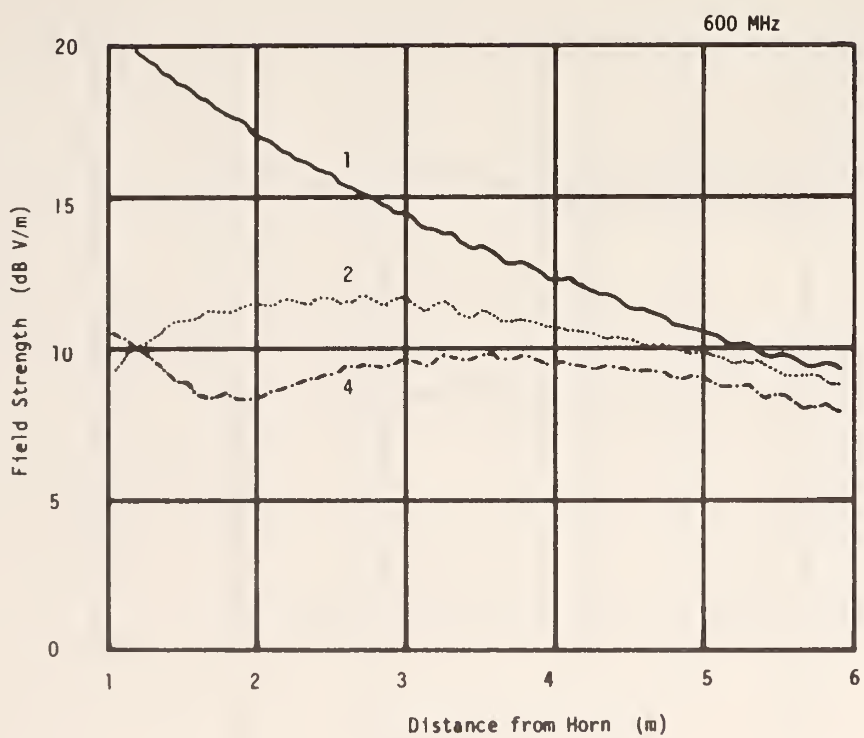


Figure 10. Standard deviation versus distance from OEG calculated from scans shown in figure 9.



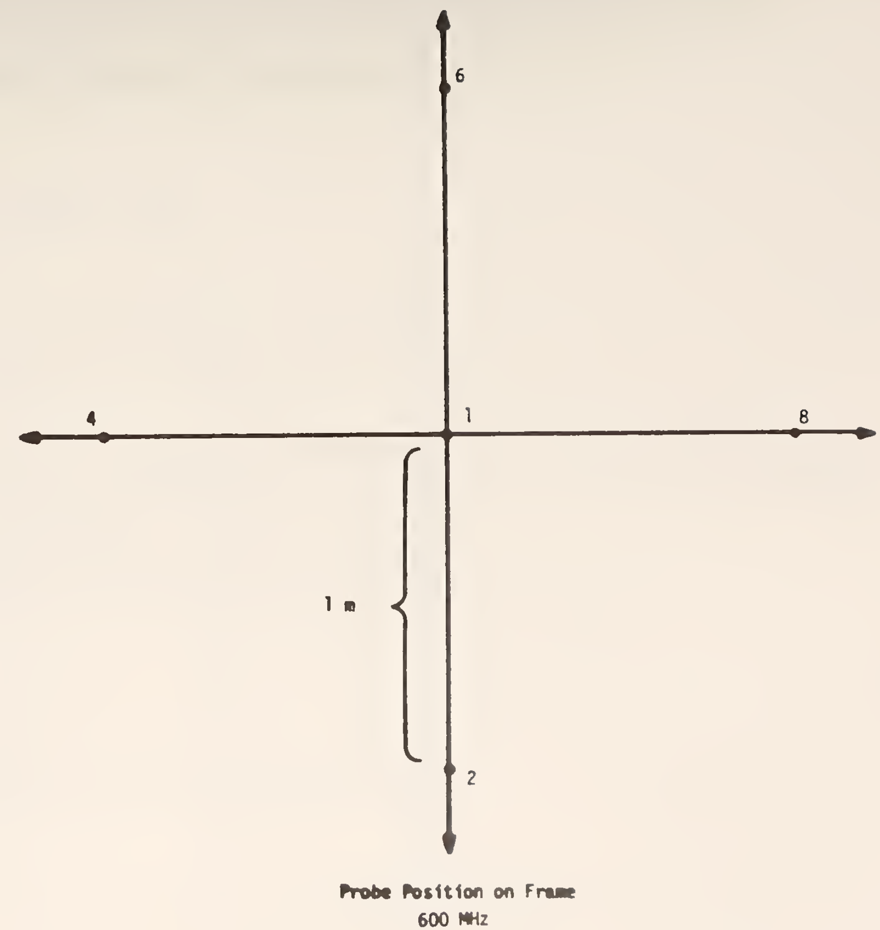


Figure 11. a) Field strength versus distance from horn for 1 m off-axis position at 600 MHz. b) Locations of probe on frame for scans.

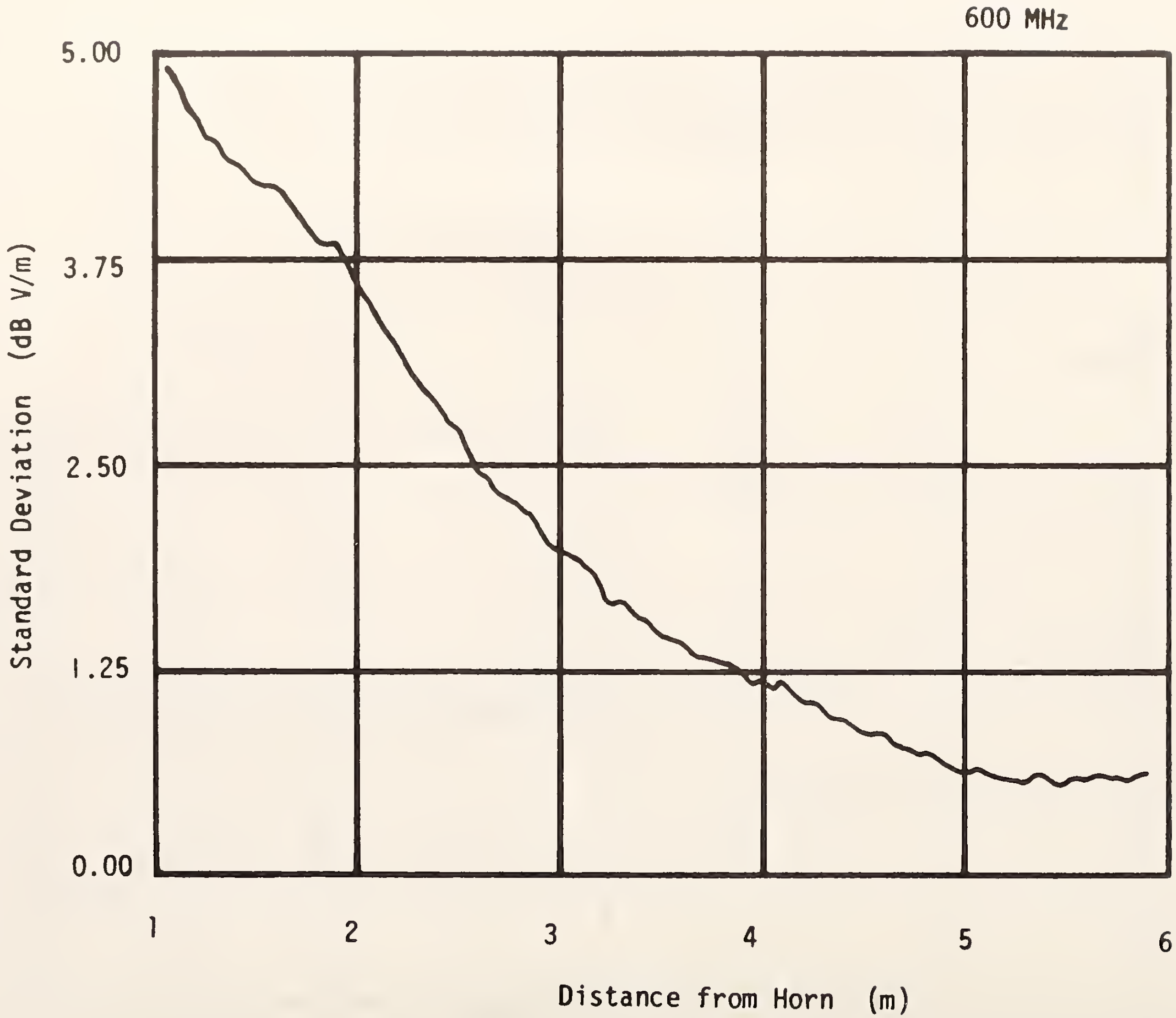
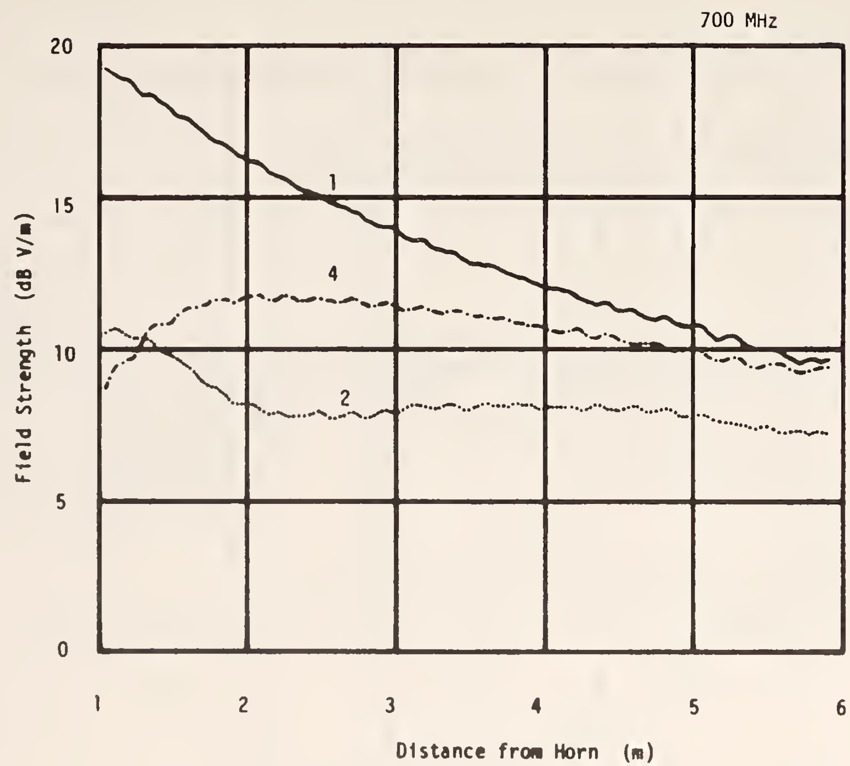


Figure 12. Standard deviation versus distance from horn for scans shown in figure 11.



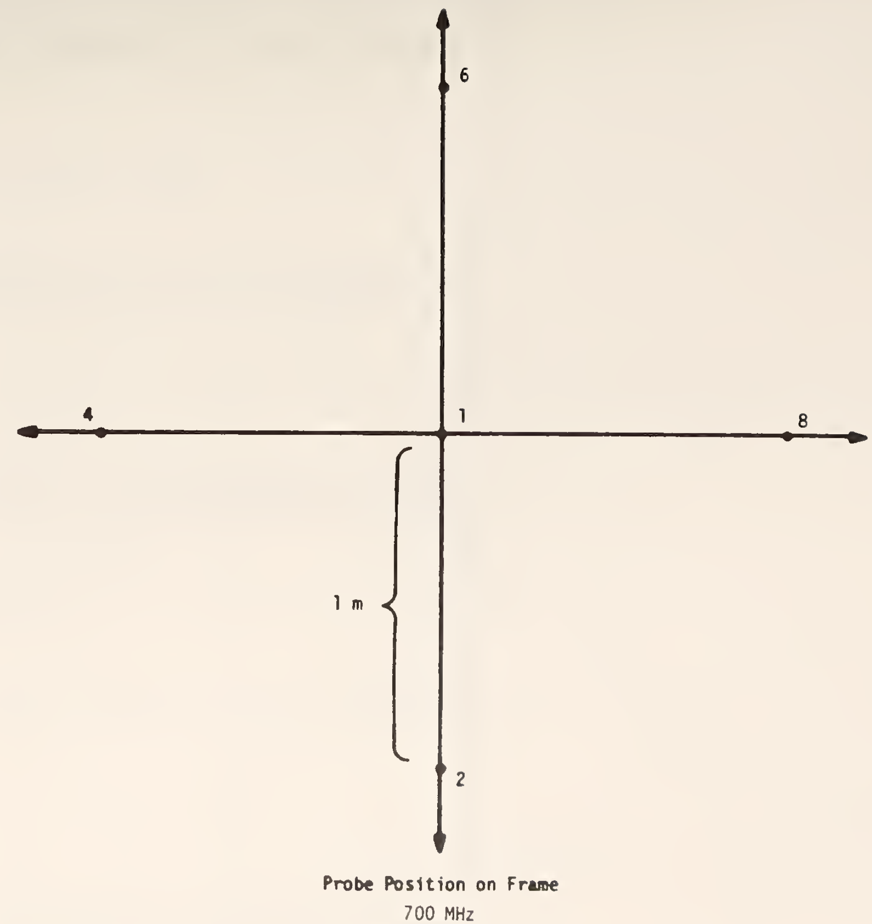


Figure 13. a) Field strength versus distance from horn for 1 m off-axis position at 700 MHz. b) Locations of probe for these scans.

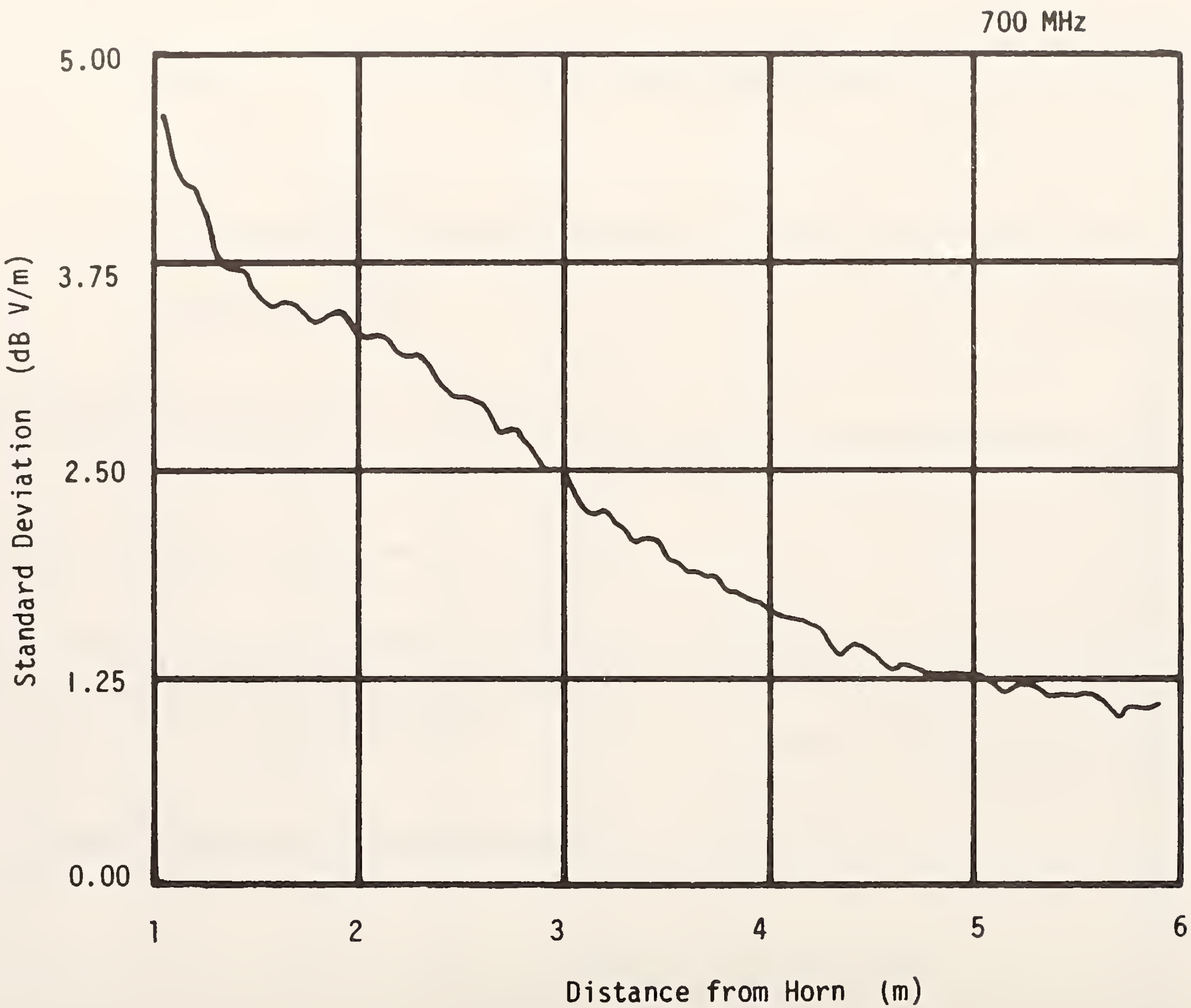


Figure 14. Standard deviation versus distance from horn for scans shown in figure 13.

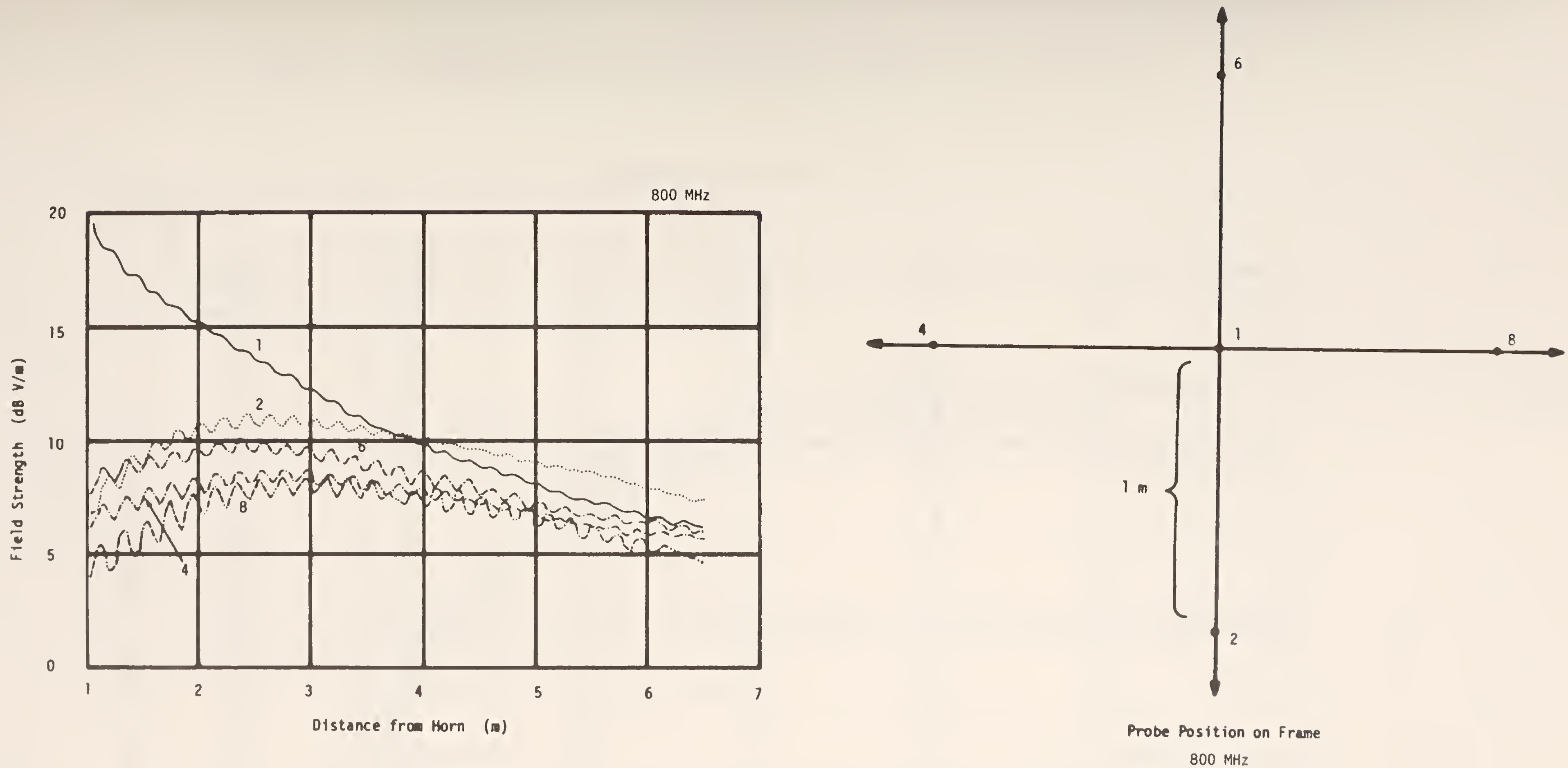


Figure 15. a) Field strength versus distance from horn for 1 m off-axis positions at 800 MHz. b) Locations of probe.

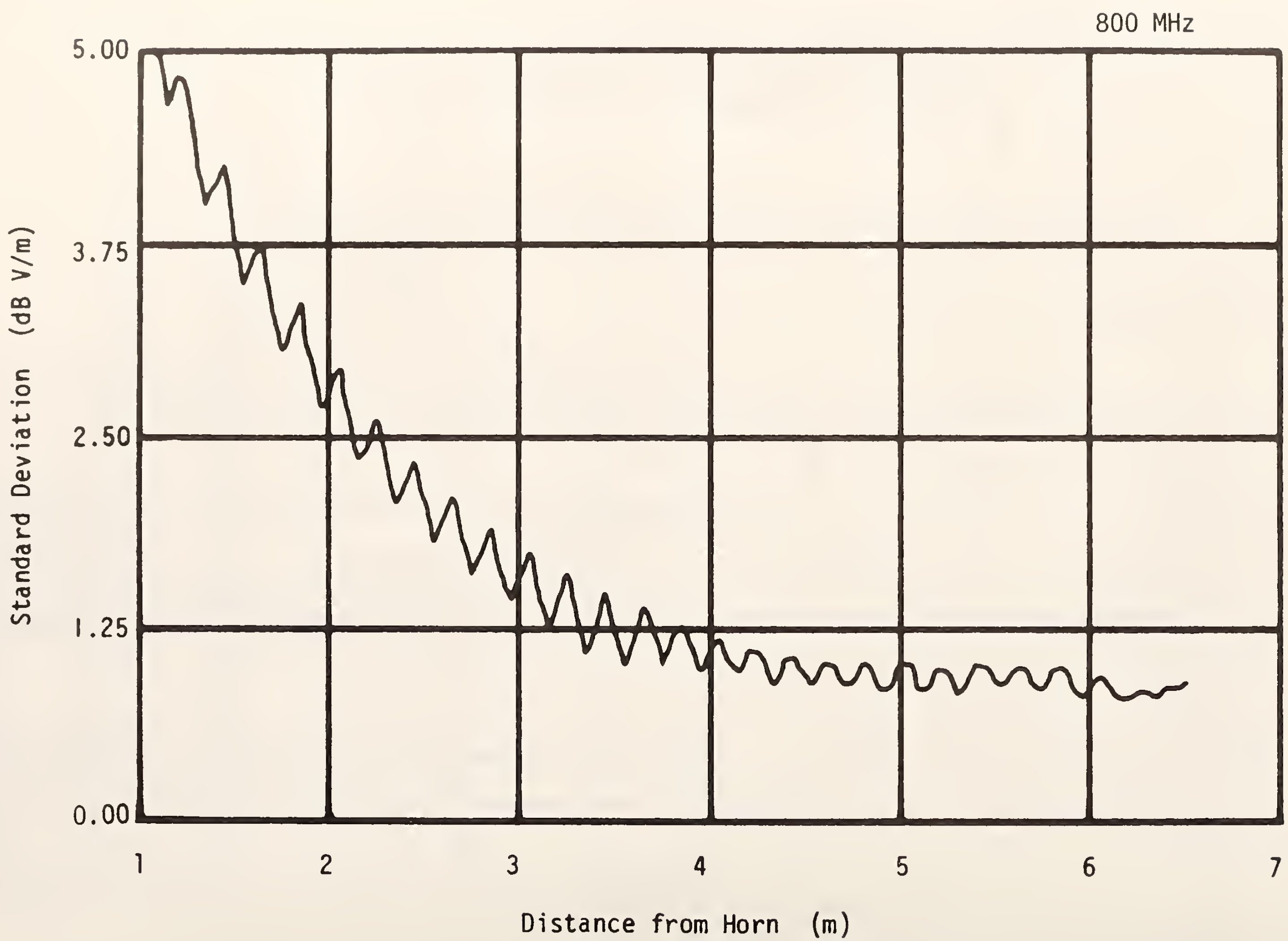
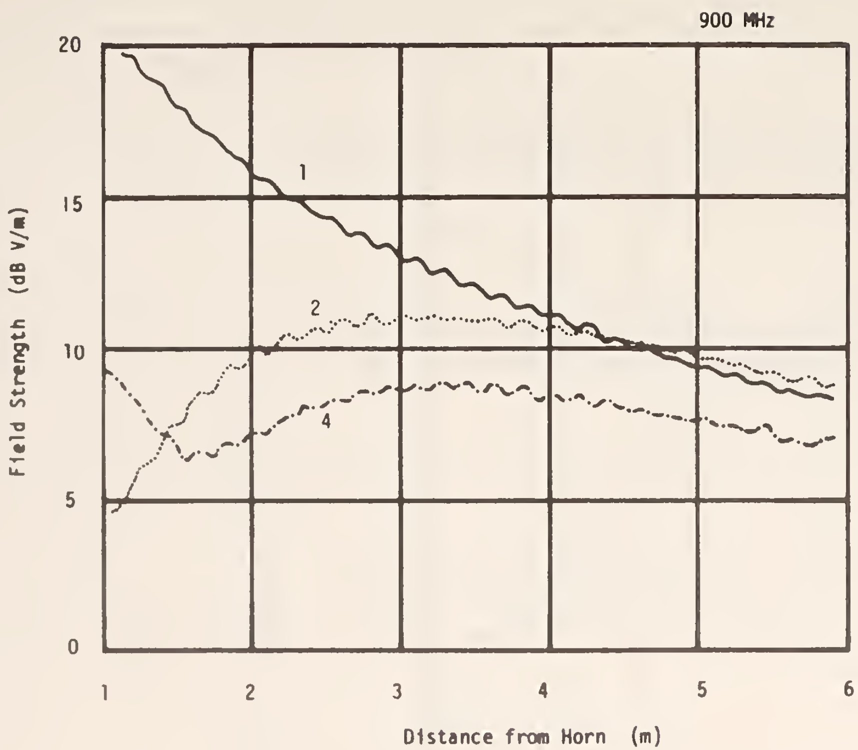


Figure 16. Standard deviation versus distance from horn for scans in figure 15a.



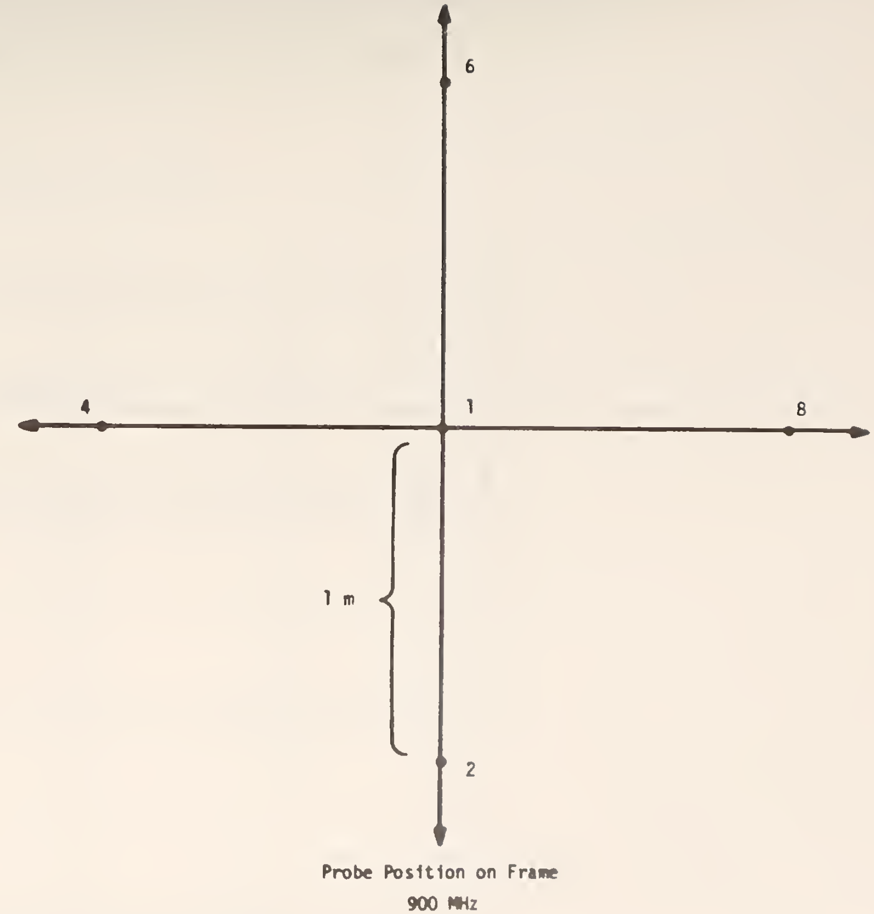


Figure 17. a) Field strength versus distance from horn for 1 m off-axis positions at 900 MHz. b) Locations of probe.

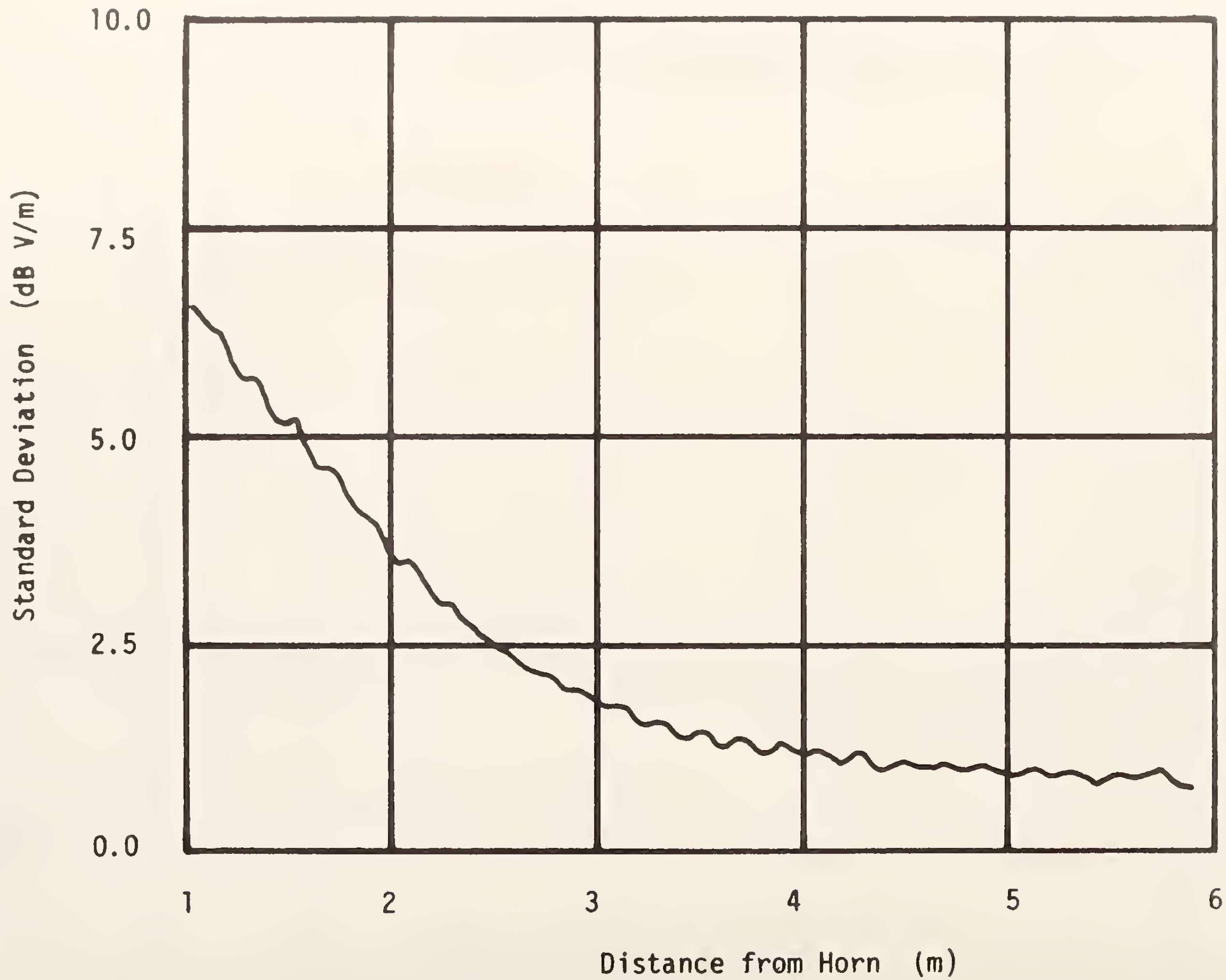
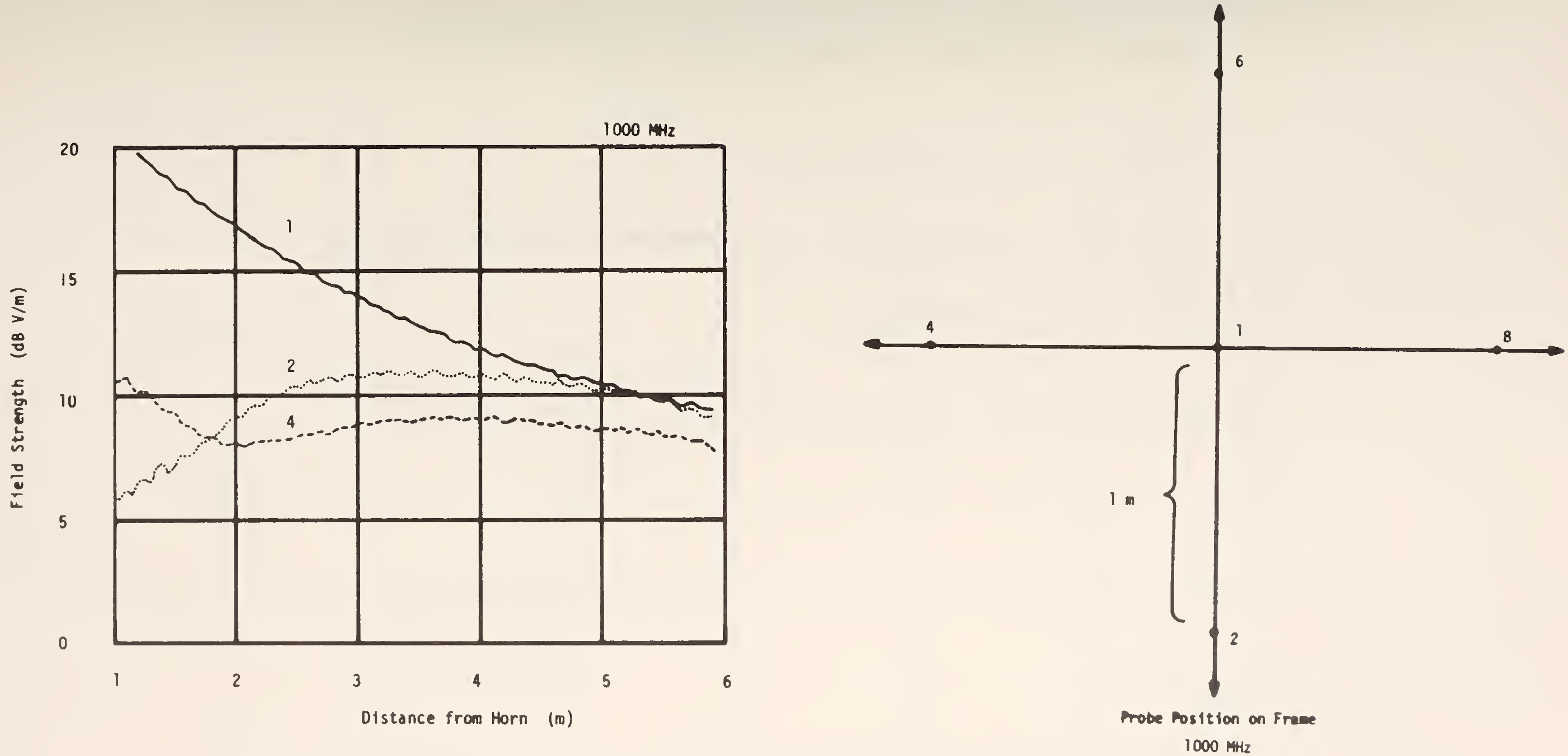


Figure 18. Standard deviation versus distance from horn for scans shown in figure 17a.



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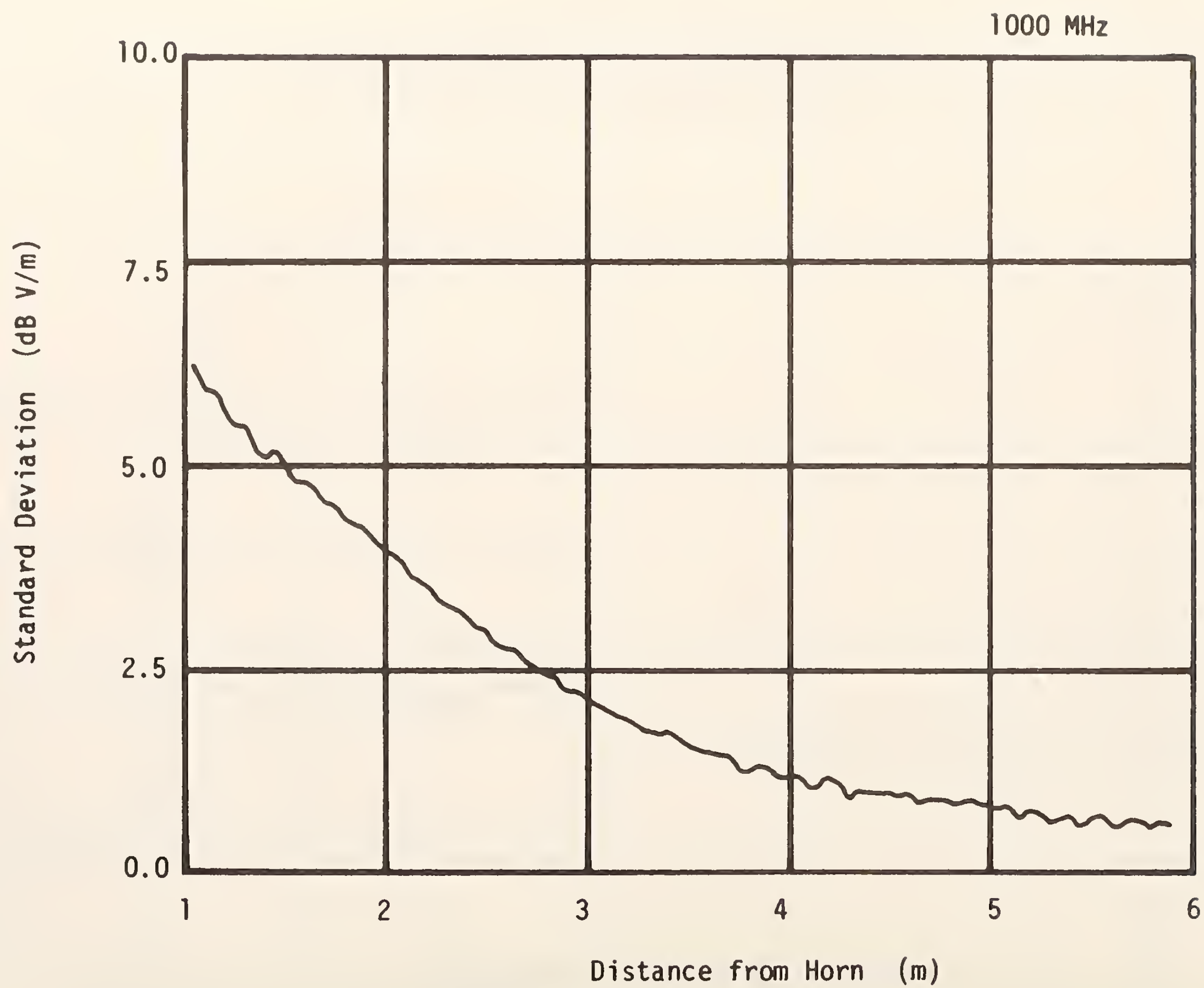
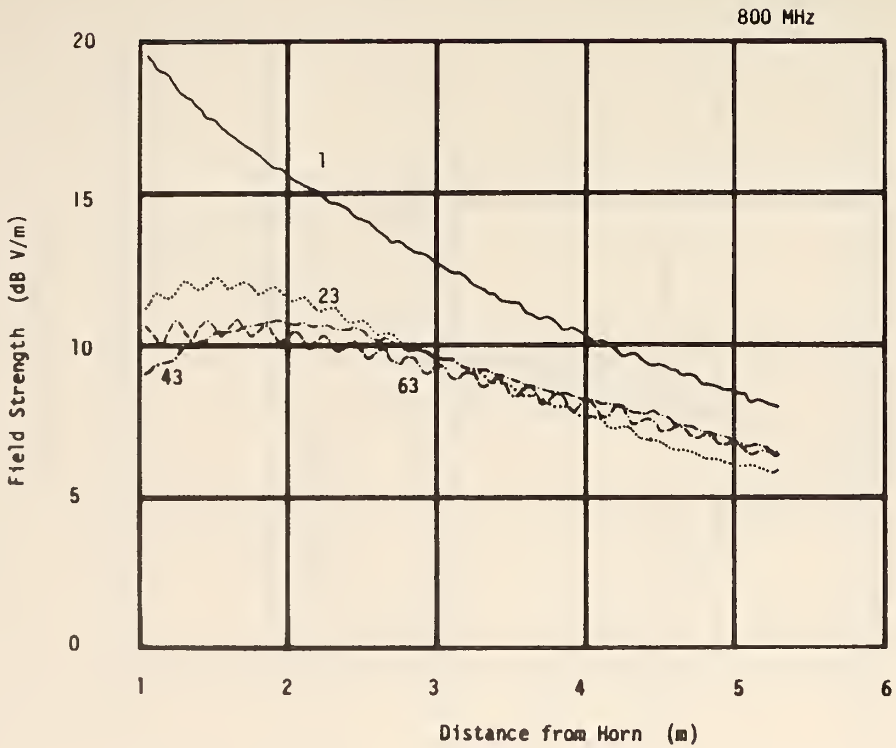


Figure 20. Standard deviation versus distance from horn for scans shown in figure 19a.



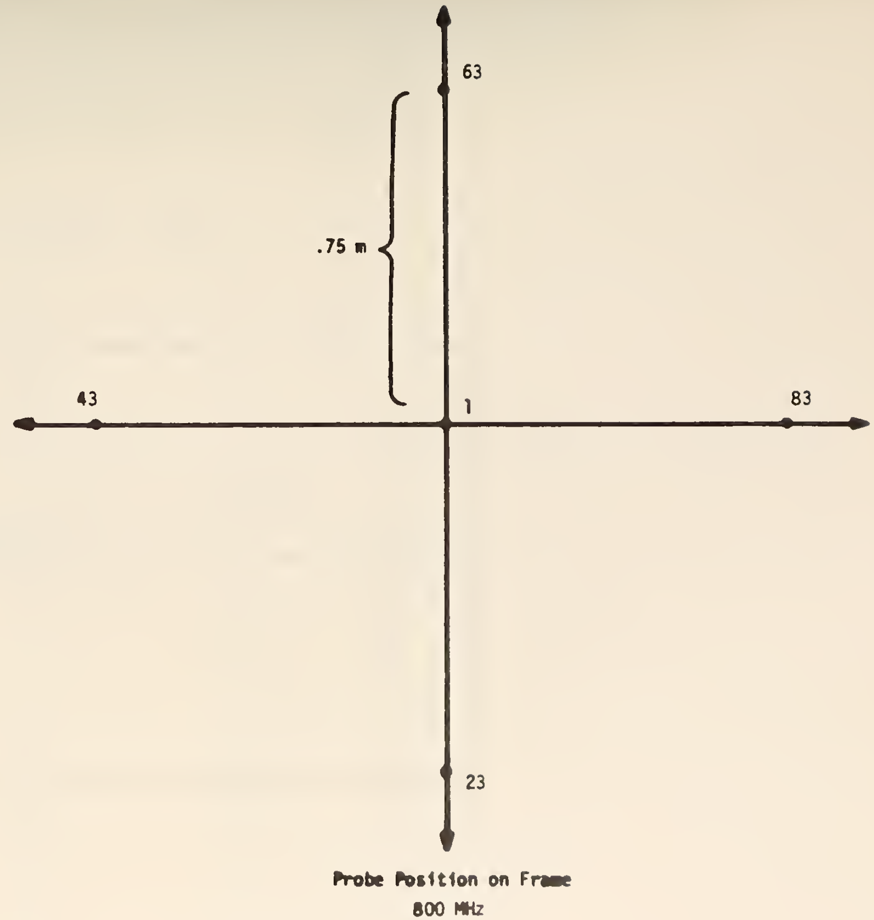


Figure 21. a) Field strength versus distance from horn for 75 cm off-axis positions at 800 MHz. b) Locations of probe.

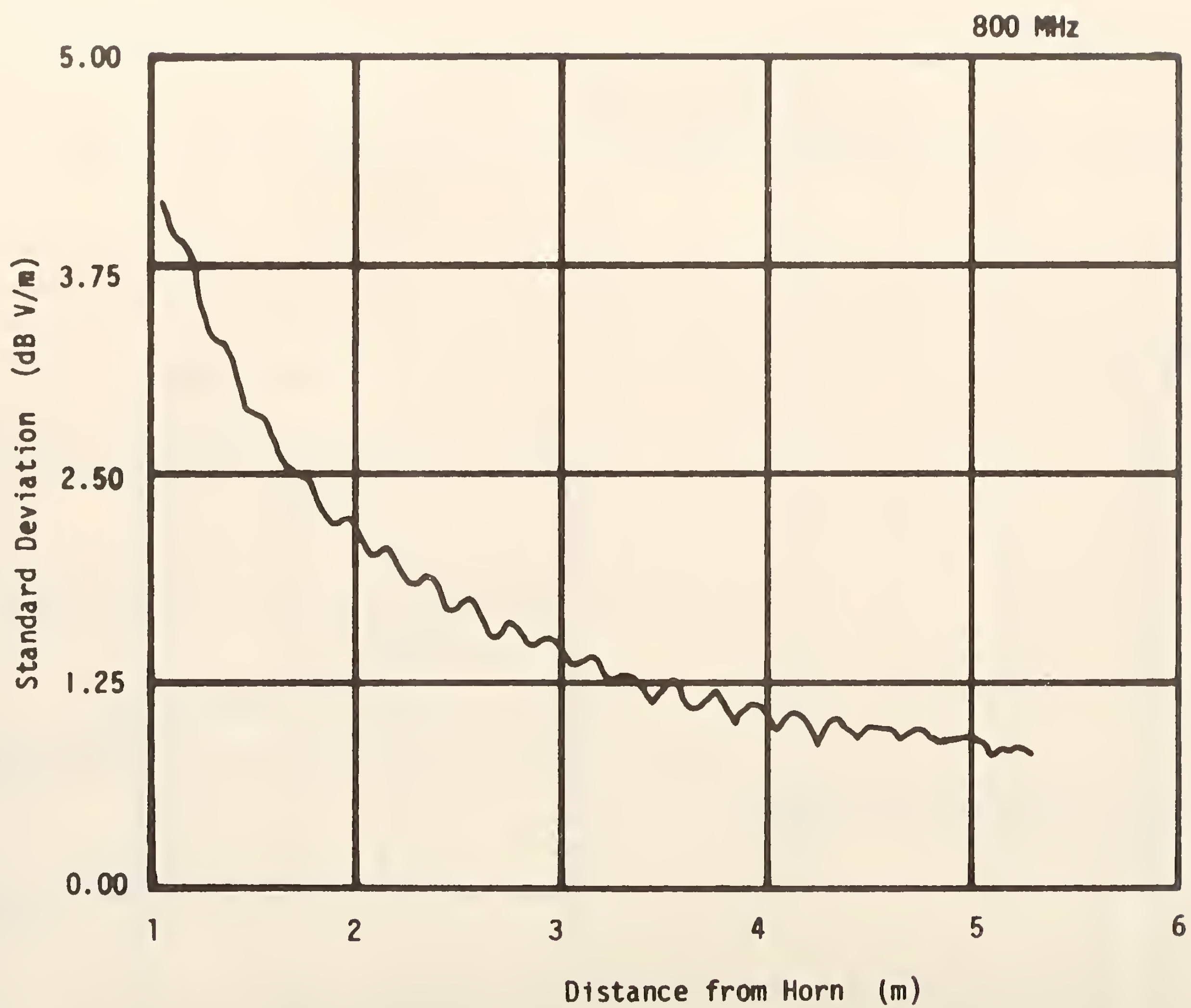
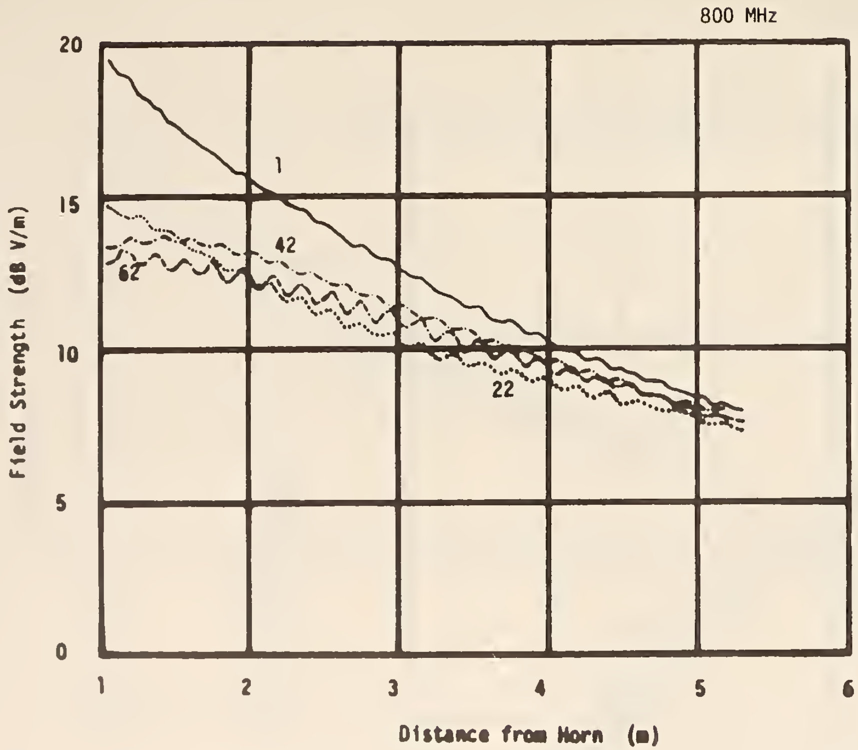
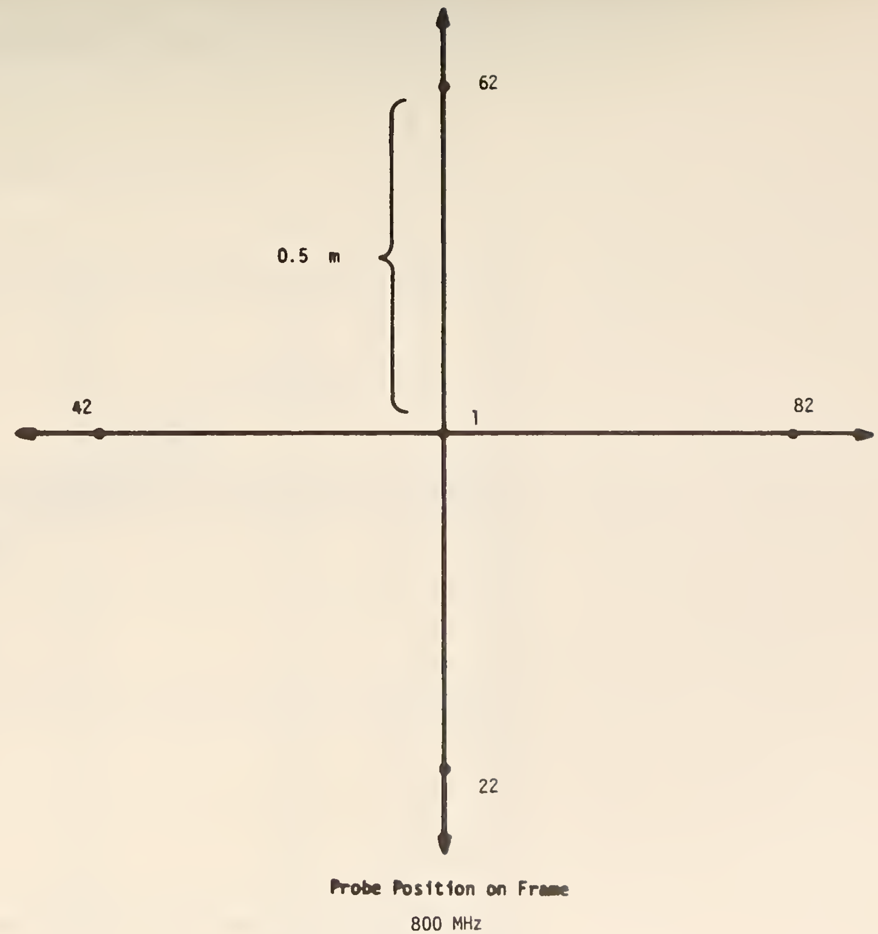


Figure 22. Standard deviation versus distance from horn for scans of figure 21a.





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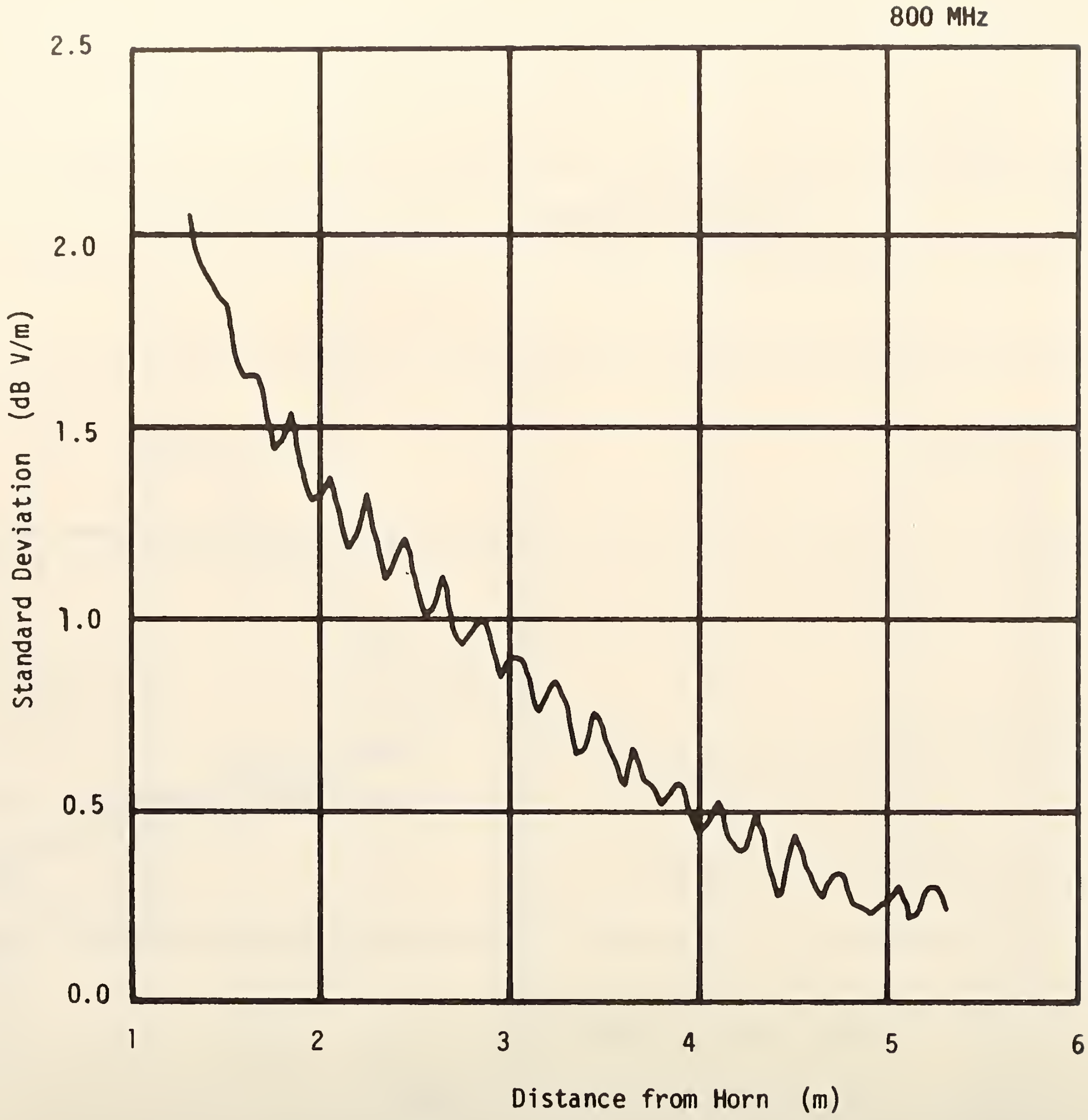

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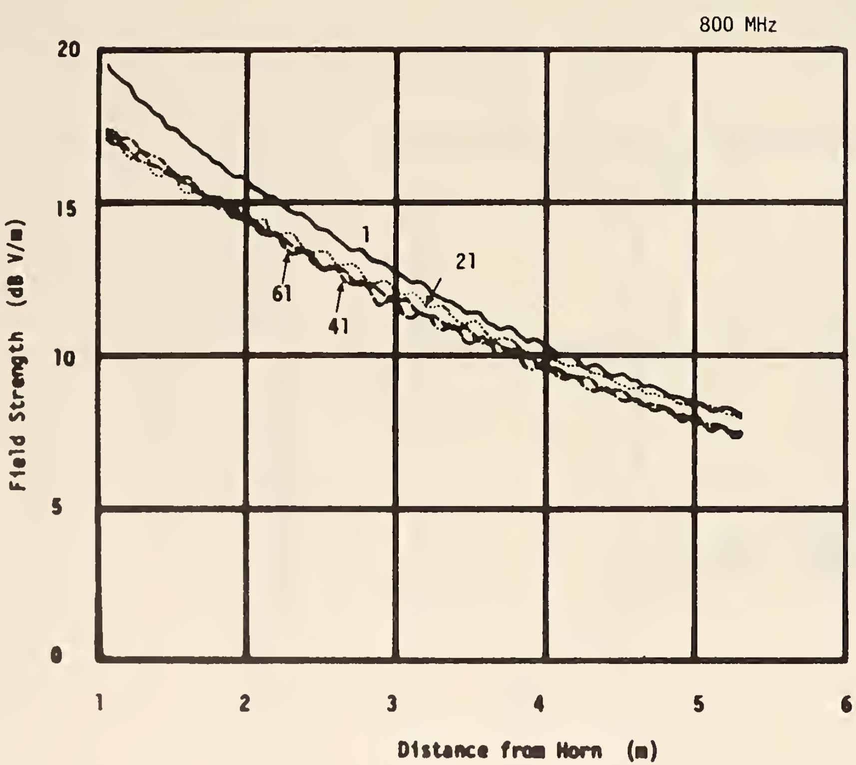

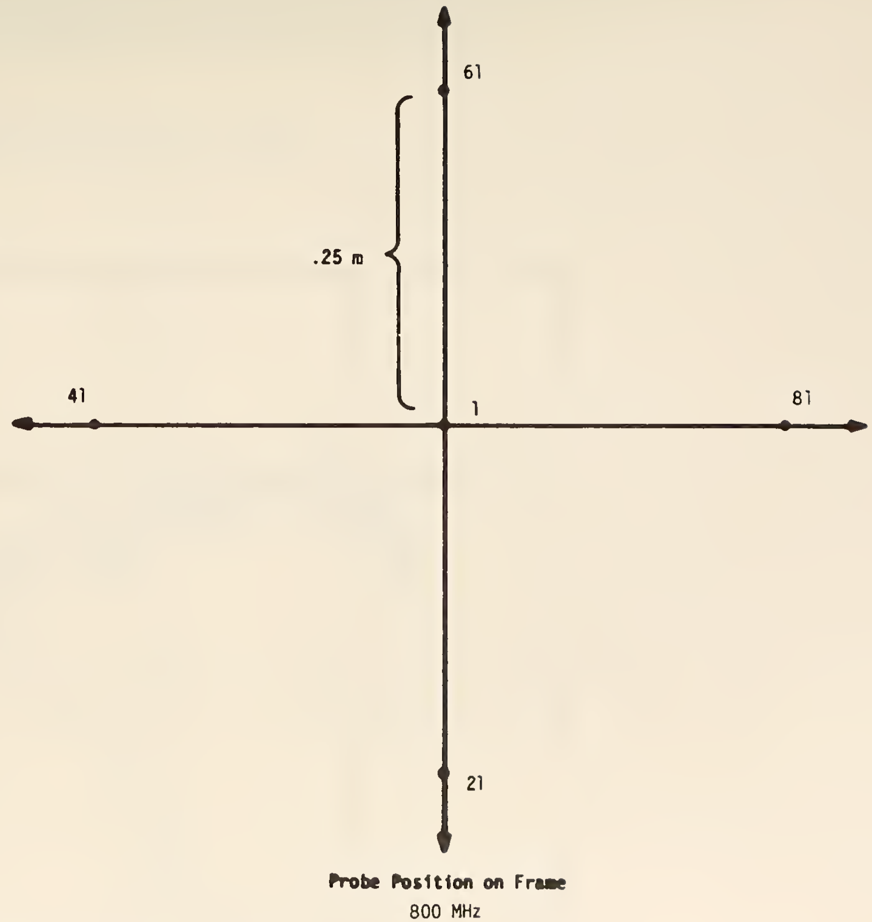

Figure 25. a) Field strengths versus distance from horn for 25 cm off-axis positions at 800 MHz. b) Locations of probe.

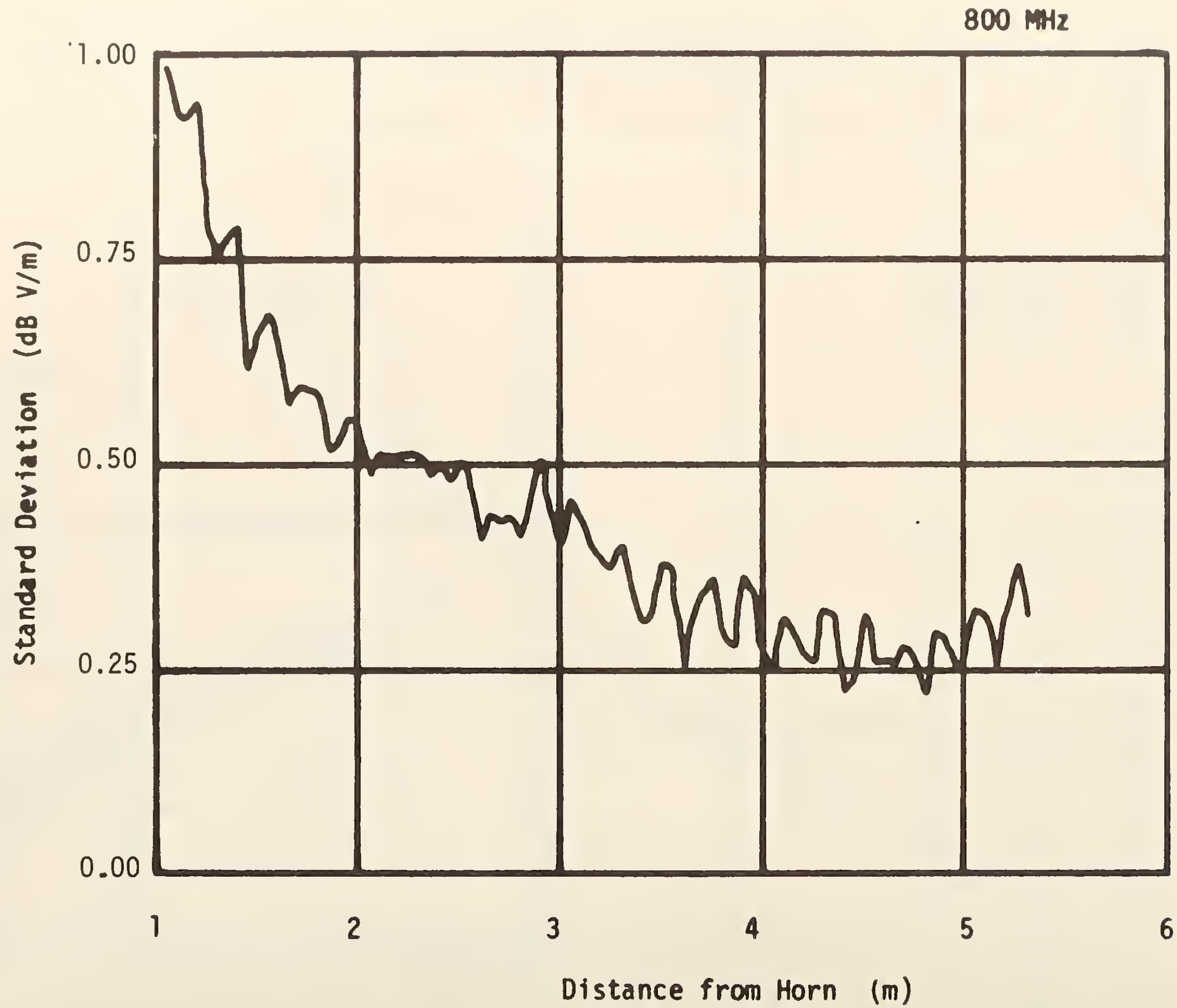

Figure 26. Standard deviation versus distance from horn for scans of figure 25a.

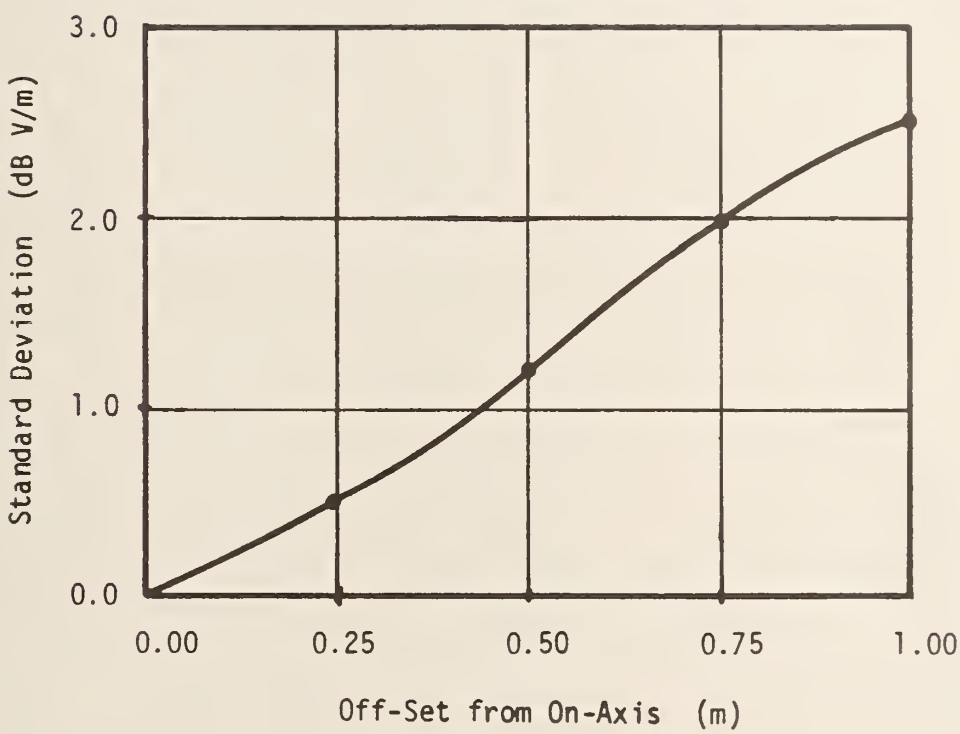

Figure 27. Standard deviation versus offset from center line at 800 MHz. In each case, the worst case standard deviation is taken for distances more than 2 m from the launching horn.

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Field strength versus distance from various source antennas is measured in a rectangular rf anechoic chamber on axes parallel to the boresight axis. An electrically small field probe is repeatedly scanned longitudinally away from the launch antenna and into the chamber. With each scan various parameters are changed, including: 1) horizontal and vertical position of the probe with respect to the center line of the launch antenna; 2) frequency, and 3) type of launch antenna. With the probe located 1 m off the center line and scanning between 2 and 6 m from the launch horn, the uncertainty due to being off the center line ranges from ±1 dB at 250 MHz to ±5.0 dB at 800 MHz and above. If the probe is within ±50 cm of center line, the uncertainty is no more than ±1.5 dB at 800 MHz; and, for ±25 cm from center line the uncertainty is further reduced to ±0.5 dB at 800 MHz.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

anechoic chamber; open-end waveguide; probe; pyramidal horn

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